SOFIA EXPERIMENTER'S HANDBOOK

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OP03-001

Book 1: Science Instrument Development Manual
Volume 1: Observatory Overview

STRATOSPHERIC OBSERVATORY FOR INFRARED ASTRONOMY (SOFIA)

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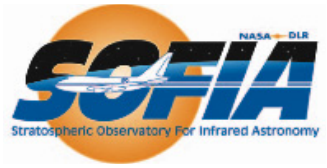

CHAPTER 0

Preface

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0.1 - Revision History

Revision	Comments

0.2 - Documentation Conventions

TBD

0.3 - Related Documents

Note: If viewing PDF and you have the documents in a common folder, you can click the link to open the document.

Book 1: Science Instrument Development Manual

Volume 1: Observatory Overview

Volume 2: Observatory Interface Control Documents

Volume 3: Observatory Airworthiness Manual

Volume 4: Post Instrument Selection Process (SI Development Planning)

Volume 5: Miscellaneous (tbd)

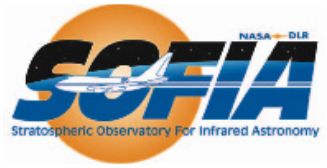
Book 2: Observing Program Guidelines

Volume 1: Applying for Observation Time

Volume 2: etc.

...

Volume n: etc.



CHAPTER 1

SOFIA Design and Operation

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1.1 - Overview of SOFIA Observatory and SSMOC

SOFIA (Stratospheric Observatory For Infrared Astronomy) carries a gyro-stabilized telescope into the dry stratosphere, to permit observations of radiation of celestial objects at wavelengths from the visual and into the far-infrared and sub-millimeter. Development of SOFIA was directly inspired by the success of the Gerard P. Kuiper Airborne Observatory, a NASA Ames aircraft that carried a gyro-stabilized 0.9-meter telescope. The development of SOFIA was an international effort, involving a consortium of European firms contracted by the German space agency, DLR, to develop the 2.7-meter SOFIA telescope. The SOFIA aircraft is a Boeing 747-SP originally configured as a commercial passenger aircraft for Pan American Airlines. The aircraft was completely overhauled and modified to accommodate the Observatory sub-systems that include: the SOFIA telescope; an on board mission control area; a telescope cavity with cavity door; and a cavity environment system. The aircraft overhaul and modification were done by a team of US companies under a NASA contract to the Universities Space Research Association (USRA). Research operations will begin on SOFIA in 2005 [TBC].

USRA, under the same contracted by NASA, will operate the SOFIA Observatory for NASA and DLR. Operations of SOFIA will be out of NASA Ames Research Center, where the Observatory (i.e., the aircraft with the telescope and other mission sub-systems) will be housed in hangar N211. USRA will run the SOFIA Science & Mission Operations Center, the SSMOC, in the same hanger. This center will run all mission operations including flight preparation, mission planning, observatory and aircraft maintenance, science planning, and the acquisition and retrieval of science data. The SSMOC will also maintain a Data Archive of all SOFIA data.

The Science Instruments used on SOFIA are all built by the science community. USRA will release a Call for Instrument Proposals for the development of USA SOFIA science instruments every three years once SOFIA is in full operation. Funds will be awarded based on a peer review process. More details on this process are in Chapter 5. The German science community also develops science instruments for SOFIA; their funding is under a different process.

This overview chapter of the Experimenter's Handbook (Chapter 1) is to familiarize a new or potential SOFIA SI developer with the SOFIA Observatory and SSMOC. Other chapters in this handbook will address the observatory interface requirements that must be met by SI developers of SOFIA instruments and SI Teams using the observatory, and general SOFIA operations information pertaining to readying a SI at the SSMOC for flight and data acquisition (i.e., observing) and data archiving.

1.2 - General Description of Observatory Working Environment

1.2.1 - Observatory Floor Plan

A schematic layout of the Observatory onboard "Mission Control" area is shown in Figure 1-1, and includes the location of the telescope at the aft end of the cabin, the arrangement in the cabin of consoles, seating, connector panels, and other support equipment. An interior view of the main cabin is shown in Figure 1-2. On the ground, personnel and equipment access is through the first passenger side door on the port (left) side (i.e., L1 door), reached from the N211 hangar via a permanent platform. Science Instruments and associated equipment are loaded through this door. The second passenger door on the port side is also available for personnel access, but only personnel access. In the case of emergencies, all four passenger doors in the mission control area of the observatory are equipped with inflatable slides/rafts for emergency egress.

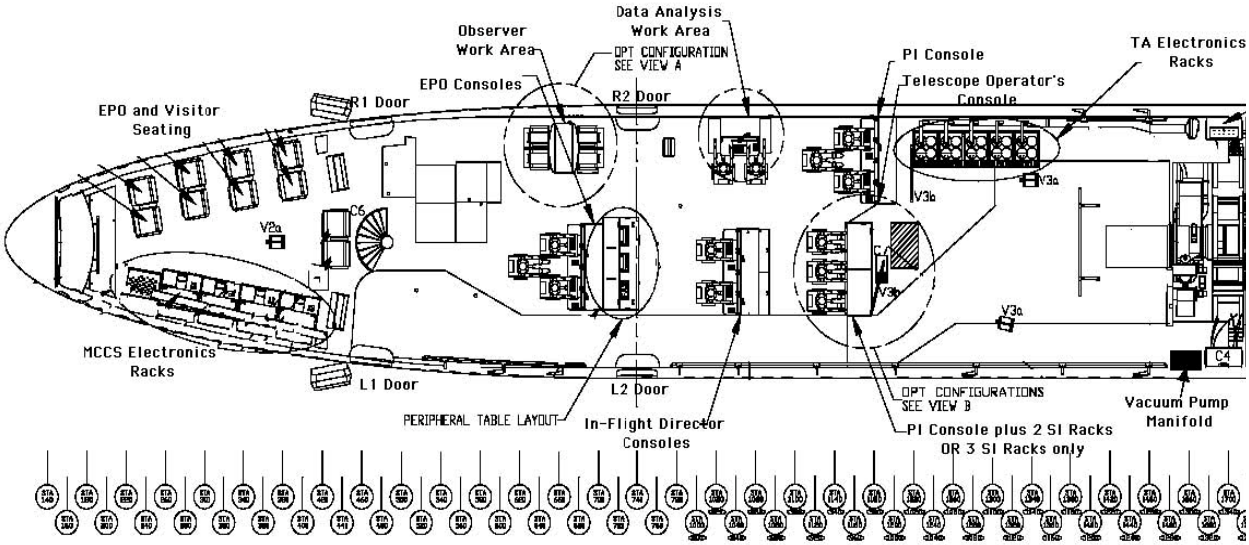

Figure 1-1. Schematic Layout of the SOFIA Cabin

Figure 1-2. Aft Cabin Mission Control Area

1.2.1.1 - SI Team Work Areas

Figure 1-1 shows four areas in the mission control area belonging to SI team members:

1. The prime area is where the SI electronics and computer are located, ~20 feet aft of the SI mounted to the telescope, in an area allowing for three SI equipment racks or two such racks and a PI Console.
2. A PI console next to the Telescope Operator's console.
3. Two workstations facing outboard on the starboard side of the cabin.
4. A general working area with a table and four chairs.

The four areas seat a total of 10 people.

Note: The four seats at the table cannot be used for take-off and landing. However, there is seating available up front in the EPO/visitor area for take-off and landings.

Each PI console is as shown in Figure 1-3, and contains two workstation screens. Such consoles can display any of the Mission Control GUIs as well as run any SI Team programs/GUIs. SI team members have control the Observatory through these PI Consoles or directly through their own SI computers in work area #1. This control will be limited to observing type controls.

The science work area #3 is for quick-look analysis of data. This area will not be present at ORR (Operational Readiness Review).

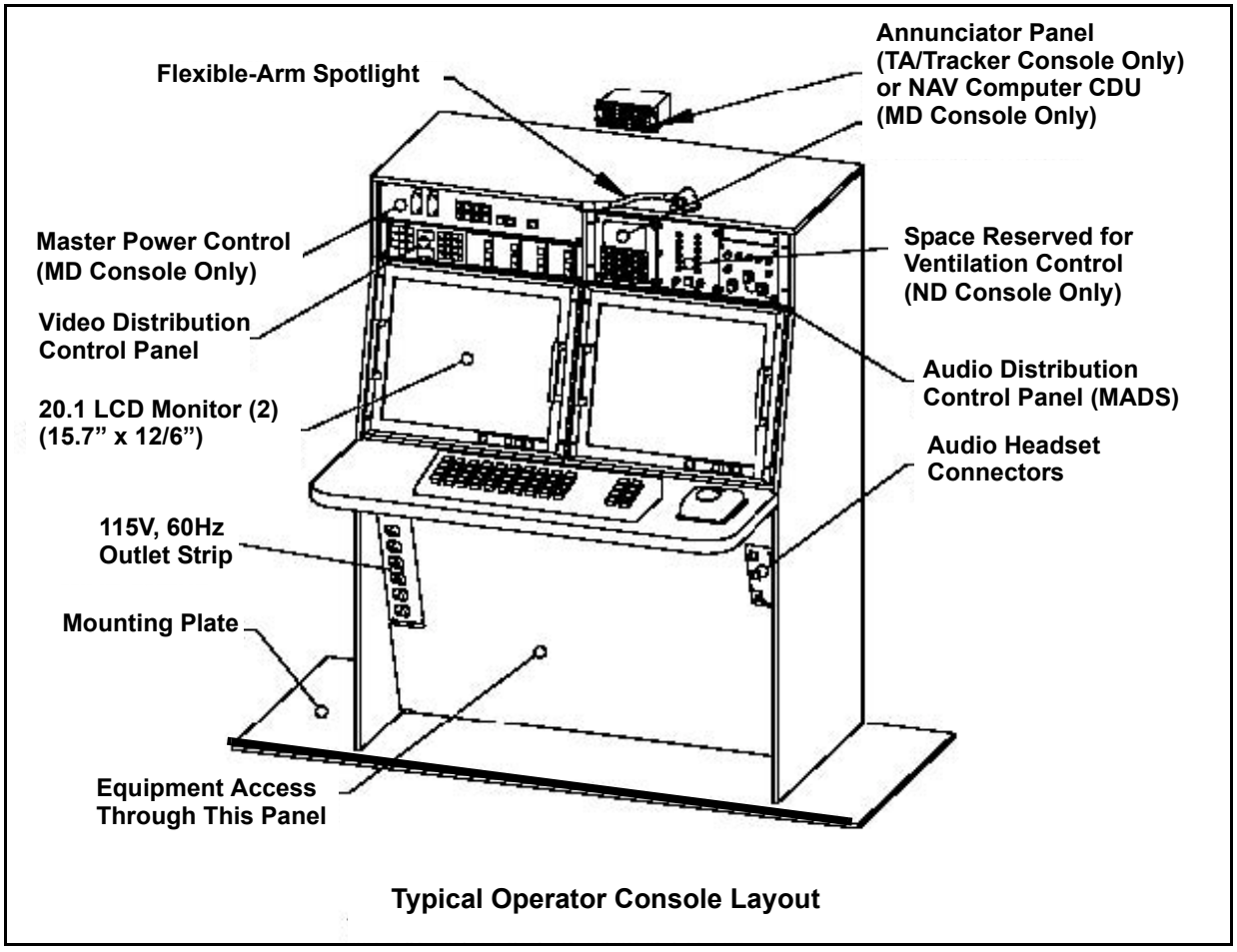
Flexible-Arm Spotlight
Annunciator Panel (TA/Tracker Console Only) or NAV Computer CDU (MD Console Only)
Master Power Control (MD Console Only)
Space Reserved for Ventilation Control (ND Console Only)
Video Distribution Control Panel
Audio Distribution Control Panel (MADS)
20.1 LCD Monitor (2) (15.7" x 12/6")
Audio Headset Connectors
115V, 60Hz Outlet Strip
Mounting Plate
Equipment Access Through This Panel
Typical Operator Console Layout

Figure 1-3. PI Console

1.2.1.2 - SI Access in Flight

During flight operations, there are safety-related limitations to access of Science Instrument (SI). Safety reviews by NASA and the USRA Team have stated that there is a safety concern associated with accessing an SI in flight while the telescope assembly (TA) is not braked. And operator in such a situation could be pinned or crushed between the SI (attached to the TA) and the aircraft, or struck by the SI. If the TA is not braked, the SI must be accessed such that the operator cannot be injured. Injury can be avoided by using an "SI safety barrier,"

Figure 1-4 shows a concept of the "SI safety barrier," constructed of removable, modular barriers placed during flight to demarcate the SI dynamic envelop (i.e., the volume that can be swept-out by an SI as the telescope moves within its observing limits).

These in-flight procedures must be followed to access the SI in flight:

1. If the telescope is to remain operating and unbraked while the SI is accessed, or if SI team members must move aft of the netting restraint (see Figure 1-4), then:
   a. Approval to access the SI, or move aft of the netting restraint, must first be given by the flight crew and In-Flight Director;
   b. SI access is restricted to the forward face of SI, or any part of the SI accessible from the forward side of the barrier railing; and
   c. No disconnecting or re-connecting of high-voltage or power lines is allowed in flight.
2. If access to parts of the SI inaccessible for a person forward of the barrier is required, then:
   a. Approval to access the SI must first be given by the flight crew and In-Flight Director;
   b. The In-Flight Director will turn a Key Activation Switch on the console to brake the TA, thus enabling the key to be removed from the console;
   c. The key is then used by an experienced/trained SI team member to open the barrier gate to access the SI beyond the forward face;
   d. No interference with the SI seals or Access Port seals is allowed in flight while the TA gate valve is open; and
   e. No disconnecting or re-connecting of high-voltage or power lines is allowed in flight.

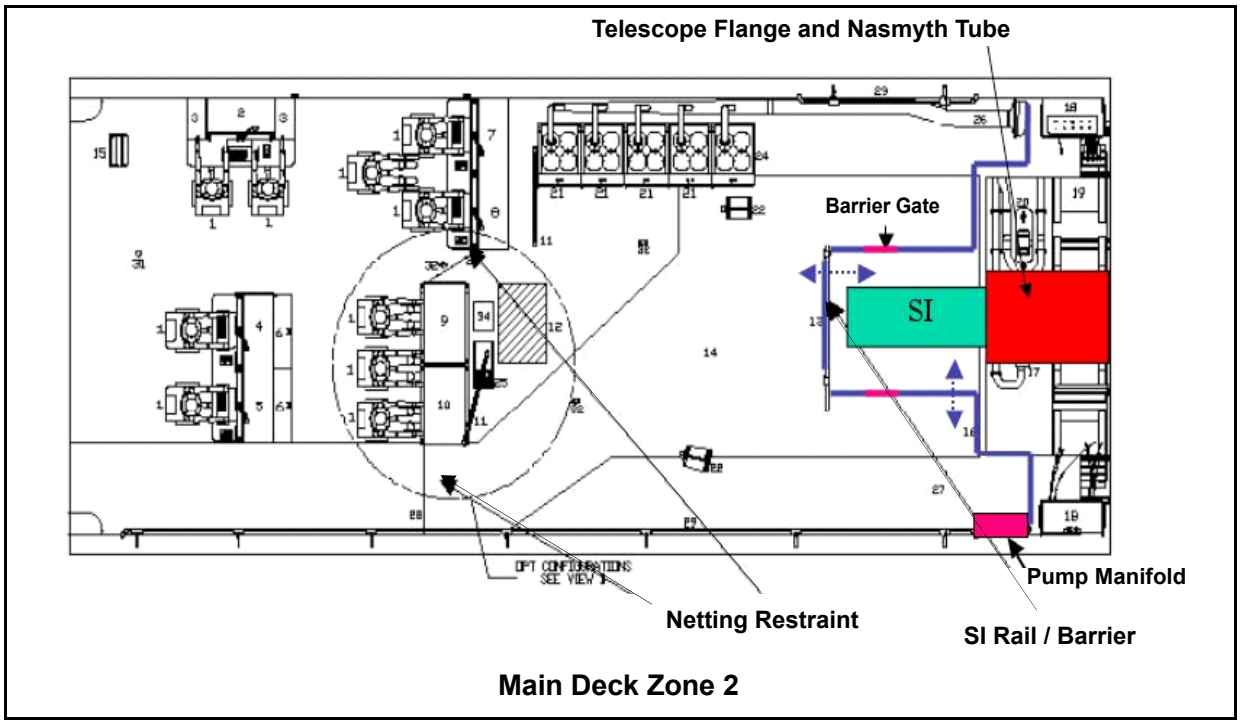

Figure 1-4. SI Safety Barrier

1.2.2 - Observatory Cabin Environment

Although all effort was taken to maintain as much as possible the same levels of noise in the Observatory as on a normal passenger aircraft, the opening in the aft fuselage for the telescope

adds noticeably to the cabin noise level, which has been measured to be in excess of TBD decibels. This noise level in the cabin may interfere with conversations, and may have adverse effects on experiment apparatus. Headsets for the mission audio distribution system (MADS) provided to all flight personnel substantially reduce the apparent noise level and provide adequate ear protection. However, SOFIA science instrument designers should consider the effect of the high acoustic noise level on beam-splitters, detectors, or other sensitive hardware.

Cabin temperature is maintained at about +20 °C (TBV) during flight. Cabin temperatures on the ground may be at least 5 C above the outside ambient, especially if on-board equipment is being operated and ground air-conditioning is not provided. Relative humidity in the cabin at observing altitudes is generally less than 10%.

Focal-plane instruments are mounted onto the forward end of the telescope assembly that extends into the pressurized cabin. In this arrangement, the instrument also serves as the barrier between the pressurized cabin and the un-pressurized telescope cavity.

The pressure differential between the cabin and the telescope cavity is automatically maintained at 8.2 psi (TBV) or less.

1.2.3 - Observatory Cabin Accommodations

Seating for three members of the P.I. team is located about 20 feet (TBV) forward of the telescope assembly. These seats are installed close to the forward face of the P.I. instrument racks. For this reason, these seats have both lap belts and shoulder harnesses (TBV). The shoulder harness must be used with the lap belt during takeoff and landing. The same seat belt configuration is used in the PI Console next to the Telescope Operator's Console and on the two seats facing outboard at the data analysis consoles. These latter two seats must be swiveled to face aft for landings and take-off. Additional unassigned seating is located in the forward cabin, these will have normal lap belt seat belts required for take-off and landing. During turbulence, all must be seated with their lap-belts fastened.

A typical research flight is long (~ 8 hours); two small ovens, a refrigerator, and cold drinking water are available for passenger use in the forward galley area. Two lavatories are located in the forward area, aft of the aircraft stair well.

Life-vests, life rafts, oxygen supplies, fire extinguishers, and other safety equipment are distributed throughout the cabin. All passengers will be thoroughly instructed in safety procedures prior to each flight series. Additional aircraft safety information is provided at the end of Section 3 (TBD).

1.2.4 - Observatory Personnel

The SOFIA 747-SP flight crew consists of the Captain, First Officer and Second Officer. Flight crews are provided from the staff of the USRA SOFIA program. In the main cabin, two or three members of the SOFIA SSMOC staff operate the telescope and support systems. Two crewmembers are always present in flight: they are the In-flight Director (IFD) and the Telescope Operator. A Computer Systems Specialist may also be present, especially on at least the first flight of a new flight series. These crewmembers are seated at their respective consoles. The IFD coordinates interaction of the SOFIA staff, the investigator team, and the flight crew, to assure optimum support of the research activity and safety. The telescope operator activates and controls telescope stabilization, the oscillating secondary system, and the telescope cavity environments. Finding charts and observing plans are prepared by science team members working closely with USRA staff in the SSMOC before the flight. These science planning support activities are described further below (sections TBD and TBS).

1.2.5 - Observatory Flight Profile

Two commonly used research flight profiles are shown in Figure 1-5. The initial ascent to observing altitude requires about 35 minutes. The descent and approach for landing requires at least 25 minutes. Therefore, the maximum time available at observing altitudes is approximately an hour less than the total flight duration, including heading and altitude changes. Typically, a flight is divided into 2-10 flight-legs, each leg associated with an object observed on the sky. Observing is interrupted for turns, usually taking about 2 minutes each, when going from one flight-leg to another. Observing may continue during a cruise climb to higher altitude, because of the continual monitoring of overhead water vapor (i.e., atmospheric transmission). Climb capability during the observing period is dependent on fuel load and outside air temperature. Total flight time is approximately 8.5 hours. An SI developer must assume that his/her SI must be able to hold cryogens for at least 12 hours, the probable duration between serving of an SI before and after a flight.

USRA expects to fly the SOFIA aircraft approximately 3 to 4 times a week for approximately 44 weeks of the year. NASA requires USRA to obtain approximately 960 successful flight hours per year after the initial Observatory commissioning period following ORR.

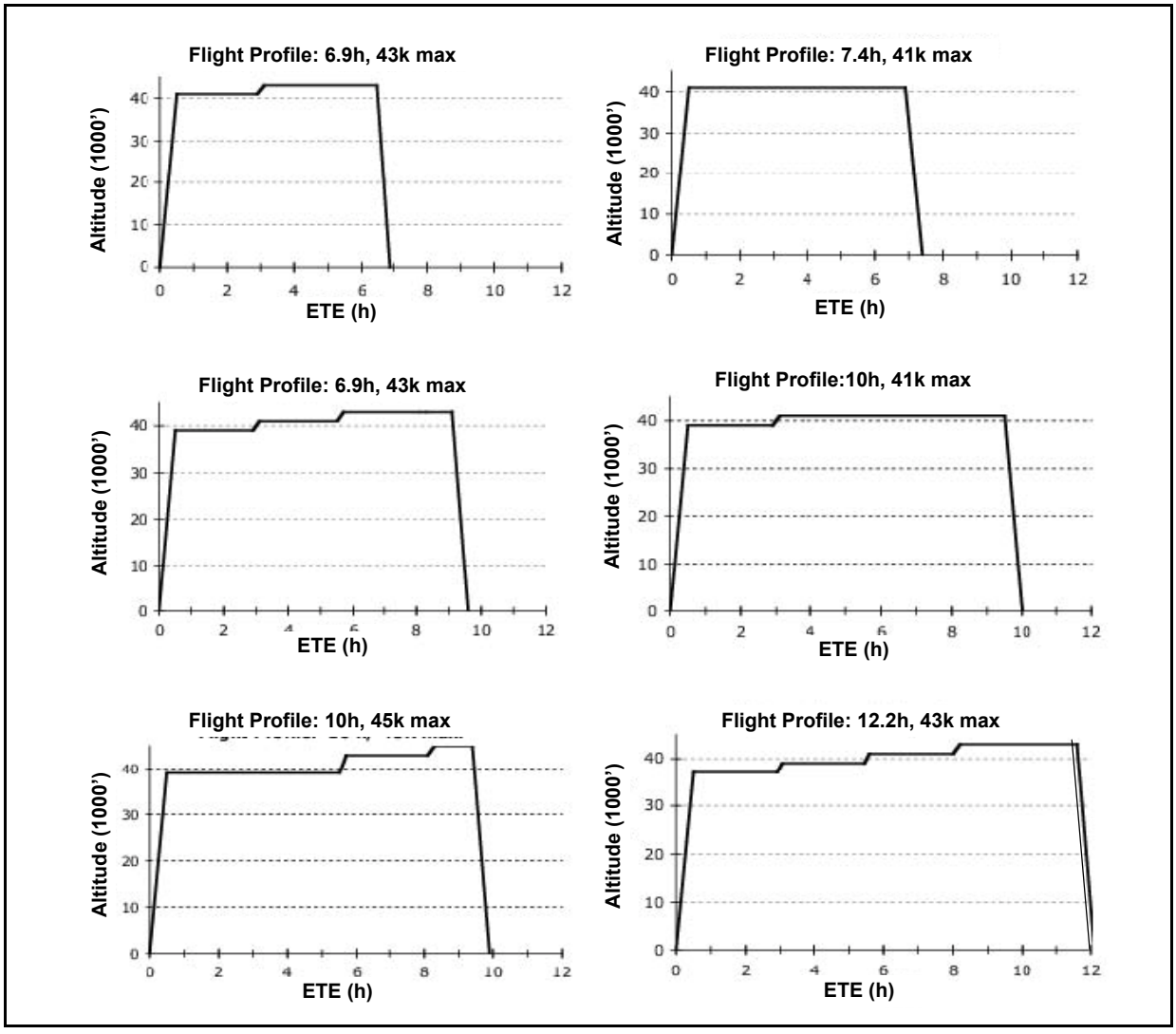

Figure 1-5. Some Typical SOFIA Research Flight Profiles

Each profile example contains nominal ~0.5-hour initial climb and ~0.5-hour final descent. Observing altitudes shown are at 37K, 39K, 41K, 43K and 45K feet pressure altitude. Usually observing may continue uninterrupted during cruise climb from one observing altitude to another. Flight at altitudes above 41K require reduced fuel load, and are limited to the final hours of the flight.

Investigators may request in advance the option of observing at an altitude of 45,000 feet. This is possible after about 7 hours flight time on a planned 8.5-hour flight.

1.3 - Telescope Design and Performance

The exposed telescope is shown in Figure 1-6. The opening or door aperture is defined by a contoured aft lip (the shear layer control) and attached rectangular frame with an overlying upper rigid door and lower flexible door. The upper rigid door is moved vertically to cover or uncover the telescope, and the lower flexible door covers any unused area below the aperture at elevation angles above the minimum. The telescope can be moved in flight through an unvignetted elevation range of 20° to 60° above the horizontal. During observing the doors are slaved to the telescope and the opening is just large enough to avoid vignetting the telescope for pointing changes of up to +/- 3° in azimuth/LOS relative to the aircraft. Therefore, the usual small aircraft heading errors do not cause vignetting or loss of pointing stability. The telescope can be operated as low as 15° and as high as 70° in elevation angle; however, vignetting will occur at these angles, since the cavity door can only cover the elevation range of 20 to 60°.

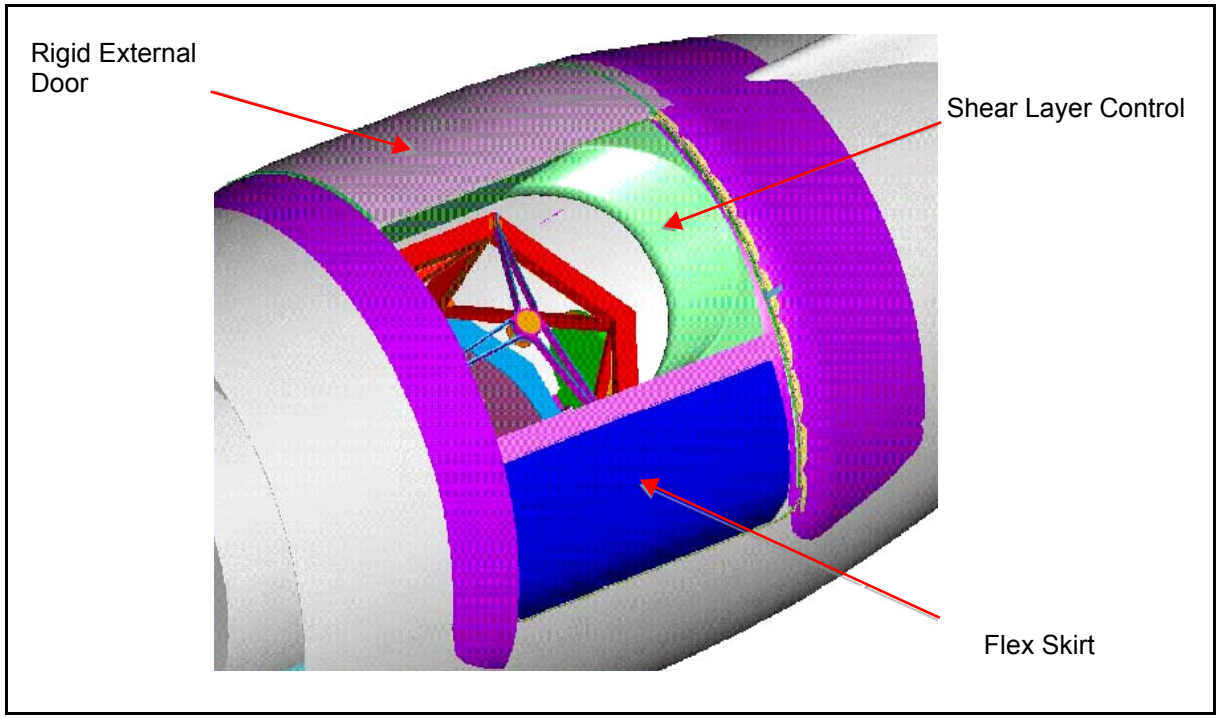

Figure 1-6. Exposed Telescope

The external appearance of the exposed SOFIA telescope showing the upper rigid door, the lower flexible door, and the passive flow control fairing. The telescope and upper rigid door are at an elevation of 20°. The apertures of the Wide Field Imager and the Fine Field Imager (not shown) are in the upper left and lower left forward corner of the telescope head ring.

1.3.1 - Telescope Design

A diagram of the telescope assembly at 90° in elevation is shown in Figure 1-7. The carbon fiber reinforced plastic telescope frame is designed to be light-weight with minimum flexure and low thermal expansion. Two guide cameras for acquisition and tracking are installed in the telescope's forward portion of the head ring. The cavity side telescope frame (or "metering structure") is attached to the aft side of a steel hydrostatic bearing, 48-inches in diameter. This hydrostatic bearing is the single suspension point for the entire telescope/instrument assembly. The hydrostatic-bearing and its matching spherical socket (also part of the telescope assembly and called the "inner cradle") are embedded in the forward cavity pressure bulkhead.

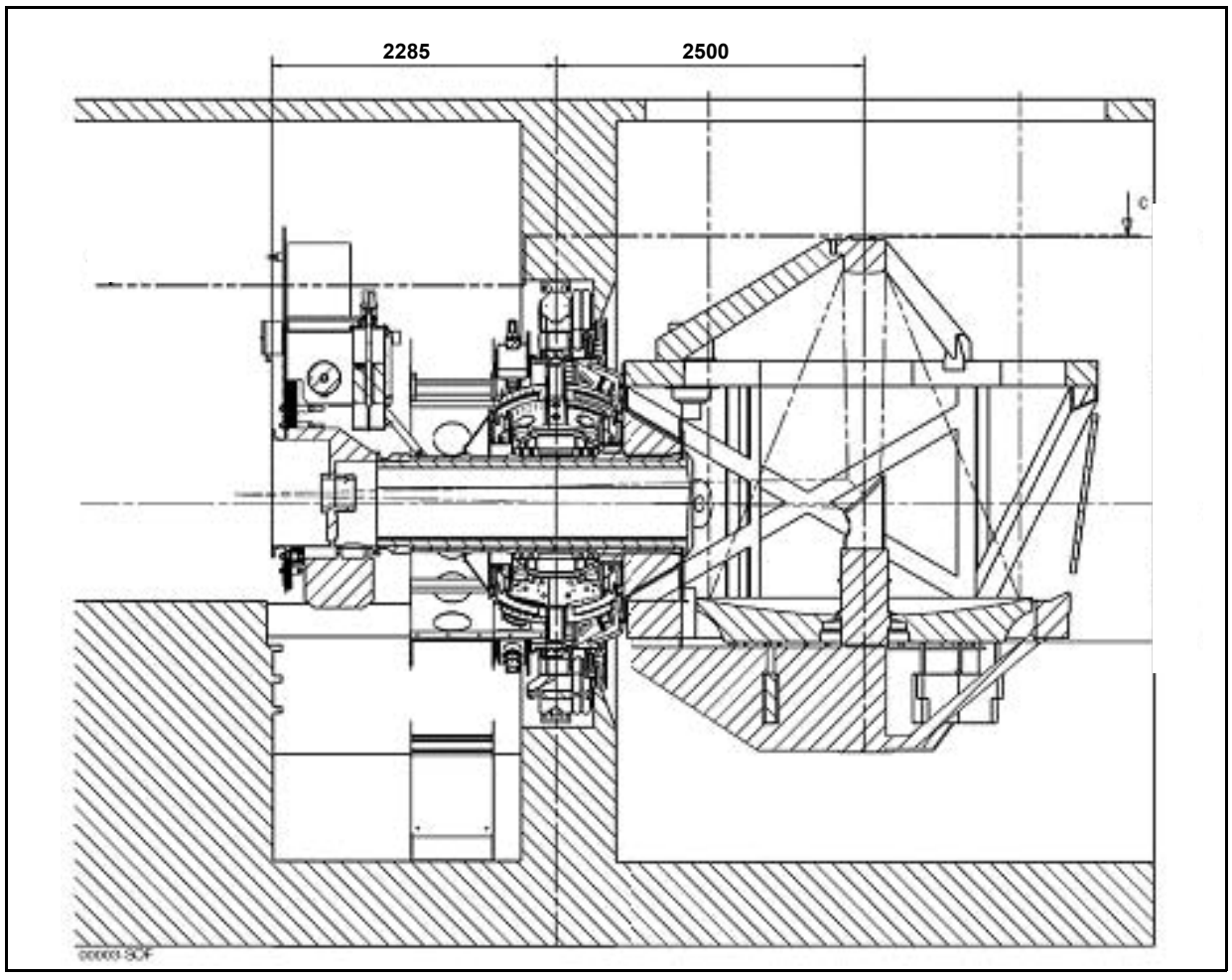

Figure 1-7. Diagram of the Telescope Assembly

In this schematic cross-section, the SOFIA telescope and some features of the cavity opening have been rotated beyond the normal telescope elevation range into the vertical plane. The cavity door and its D-shaped aperture are slaved to the telescope elevation angle. The passive flow control-

fairing runs along the aft edge of the cavity opening and extends over the top of the aircraft. The science instrument mounts forward of the telescope in the pressurized cabin. Approximate scale 1:TBD, Dwg ref:TBD

The telescope bearing/inner cradle system is supported by a telescope "outer cradle" attached to a ring of axial and tangential pneumatic vibration isolators – called the "Vibration Isolation System (VIS)". These isolators lie in a plane containing the center-of-mass of the telescope assembly. The VIS provides a degree of isolation from translational vibrations transmitted to the telescope through the bulkhead. The hydrostatic-bearing support effectively isolates the telescope assembly from rotational disturbances. The lowest natural frequency of the telescope assembly is about TBD Hz. The "Fine Drive System" controls motions between the inner cradle and the hydrostatic bearing (i.e., between the inner cradle and the telescope "metering structure" and optics). The "Coarse Drive System" controls motion between the outer cradle and inner cradle. During flight, the Coarse Drive can move the telescope in elevation from 15 degrees to 70 degrees; the Fine Drive can move the telescope in ± 3 degrees elevation and the azimuth and LOS directions of the telescope by ± 3 degrees in quadrature. Telescope stabilization and fine pointing are described further in the next sub-section.

The telescope "Suspension Sub-Assembly" (SUA) is the combination of the VIS, outer cradle, inner cradle, hydrostatic bearing, and both the Coarse and Fine drive systems.

The combination of the aircraft bulkhead, the telescope SUA, and the Nasmyth tube gate-valve or an SI mounted on the SI Flange form the pressure barrier between the Mission area cabin and the telescope cavity.

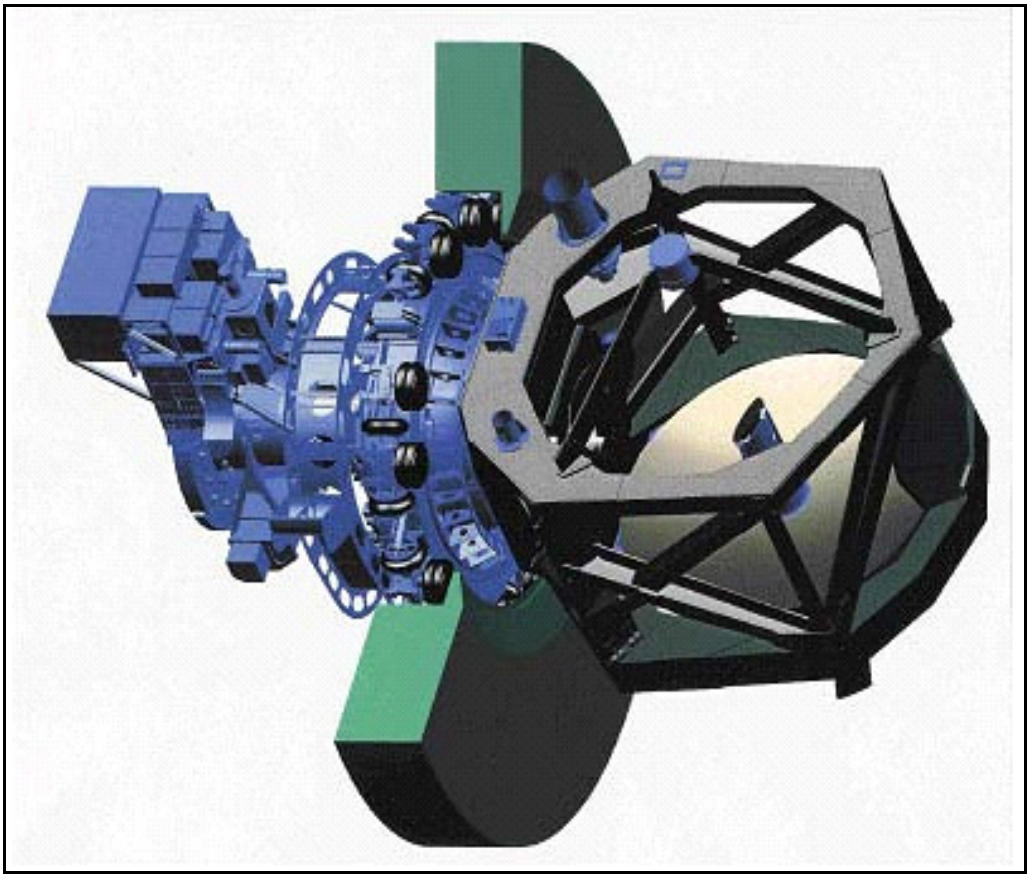

Figure 1-8. Perspective Rendering of Telescope Assembly

In this perspective view part of the aft bulkhead is cut away to expose the telescope Suspension Assembly (SUA). Some of the Vibration Isolators are visible as small black cylinders (like oreo cookies). The aft baffle is visible as a large dark plate on the aft (right) side of the telescope metering structure. Although no SI is shown, the Counterweight Rack (CWR) for SI electronics is shown as a large blue box on the upper end of the counterweight assembly, supported by braces.

1.3.1.1 - Telescope Primary Mirror Assembly (PMA)

The main telescope optics are a classical Cassegrain configuration, with a 2.7 m diameter f /1.28 paraboloidal primary mirror, and a hyperboloidal secondary mirror producing an approximately f /20 beam. An optically flat tertiary mirror with a dichroic coating reflects IR to the SI focal plane, while transmitting visible light. A second tertiary mirror reflects the visible light to the facility Focal Plane Imager (FPI). Information regarding both tertiary mirrors is included below for completeness. An alternate aluminized first tertiary is available (see section 1.3.1.3 - ”Telescope Tertiary Mirror Assembly (TMA)” on page 1-16); its dimensions are effectively identical to the dichroic tertiary. The following sub-sections briefly describe each of the main telescope optical

elements, including basic parameters, followed by a description of some properties of the integrated telescope optics. The optical surface is coated with approximately 1500 (TBC) Angstroms of aluminum with no protective overcoat. Table 1-1gives the optical parameters for the Primary Mirror.

The primary mirror is a solid (but light-weighted) Zerodur f/1.18 paraboloid of 106.5 inches (2705 mm) diameter, weighing ~800 kg. It is supported in a CFRP cell by six wiffle tree structures each with 3 attachments to the primary mirror giving axial support. In addition, there are three lateral support structures, separated by120 degrees, placed between the outer diameter of the primary mirror and the inner diameter of the support cell. The total weight of the Primary Mirror Assembly, which has a diameter of about 4 meters and a depth of 1 meter, is ~2000 kg (4409.25 lbs).

Table 1-1. Optical Parameters of the Primary Mirror

Optical Parameter	Value	Mechanical Parameter	Value
Free Optical Diameter	2690 mm	Outside Diameter	2705 mm
Focal Length	3200 mm (f/*1.28)*	Inside Diameter (central hole)	420 mm
Conic Constant	-1	Material	Zerodur
Surface roughness	10 nm (TBD)	Weight	800 kg
Wavefront Error	300 nm rms (TBD)	Thermal Time Constant	~1 hour (TBD)
Reflective Coating	100 nm Bare Al	Optical Surface Vertex Position (mm)	U = -2500 V = 0 W = -906
Reflectance *(λ 0.5 μ m)* *(λ 100 μ m)*	 0.95 (TBV) 0.99 (TBV)		
FIR Emissivity	0.05 (TBV)		
			SOF-SPE-KT-1000.0.03

The Zerodur blank was provided by Schott – Mainz, and lightweighted and polished by REOSC. Basic parameters of the Primary Mirror optical element are given in this table.

The Primary Mirror support structure includes an 18-point whiffletree, lateral supports, and interfaces to the rest of the TA metering structure. The highly-lightweighted (~85%) Primary Mirror was figured to compensate for distortion at observing elevation angles. An outer annulus 10 cm wide has slightly degraded optical figure; the undersized secondary (see below) excludes this annulus from contributing to focal-plane images.

1.3.1.2 - Telescope Secondary Mirror Assembly (SMA)

Two hyperboloid secondary mirrors are available for use, providing a back-focus range of 120 cm. The DLR secondary mirror is diamond-turned Silicon carbide with TBD Angstroms of aluminum with no protective overcoat. USRA provides a second aluminum secondary mirror with TBD

Angstroms of aluminum with no protective overcoat. Table 1-2 gives the optical parameters for both the Secondary Mirrors.

The secondary mirror is lightweighted Silicon Carbide. The secondary mirror is undersized to insure that chopping does not cause the entrance pupil to be displaced beyond the edge of the primary mirror. In addition, a central "button" ~80 mm diameter can be installed over the vertex of the secondary, to insure that the focal-plane sees only cold sky reflected in the central part of the secondary (Chapter 2, "SOFIA Science Instrument ICDs" on page 2-1). Tilt Chopping Mechanism (TCM): the secondary mirror is attached at the center of its back side to a central flexure. The distance of this flexure pivot from the vertex of the secondary mirror optical surface is included below. Focus Centering Mechanism (FCM): the TCM is mounted on a modified hexapod known as a Stewart platform. The six linear actuators can be used to provide focus and centering adjustment, and static tip/tilt of the secondary mirror and the TCM supporting it. Additional details on the function and performance of the TCM and FCM are given in Chapter 2.

Table 1-2. Optical Parameters of the Secondary Mirror

Optical Parameter	Value	Mechanical Parameter	Value
Free Optical Diameter	340/352 mm	Outside Diameter	352 mm
Radius of Curvature	954.13 mm	Inside diameter (central hole):	40 mm
Focal Length	3200 mm (f/*1.28)*	Inside Diameter (central hole)	420 mm
Conic Constant	-1.2980	Central thickness:	45 mm
Surface Roughness	16 nm (TBD)	Material	Silicon Carbide
Wavefront Error	16 nm rms	Weight	2.1 kg
Reflective Coating	100 nm Bare Al	Thermal time constant	~5 min (TBD)
Reflectance *(λ 0.5 μ m)* *(λ 100 μ m)*	 0.95 (TBV) 0.99 (TBV)	Nominal/optimum Optical surface vertex position (mm)	U = -2500 V = 0 W = +1848
FIR Emissivity	0.05 (TBV)	Distance of vertex from chop pivot point (CoG):	18 mm (TBC)
SOF-SPE-KT-1000.0.03; astrium SSM.RP.0168.1000.T.ASTR (11/7/2001)			

Basic mirror parameters are provided in this table for reference. A Secondary Mirror is mounted on a two-stage support mechanism that provides spatial chopping and control of focus, centering and static tip/tilt of secondary mirror. The Tilt Chopping Mechanism (TCM) is supported by the Focus Centering Mechanism (FCM); the latter is effectively a hexapod. The Secondary Mirror Assembly is supported above the primary mirror by three CFRP spider vanes. The secondary mirror parameters that can be changed in flight are: focus, centering, static tip/tilt, chopping frequency, amplitude, and position angle. Details concerning the operations and performance of this system are given in Chapter 2.

Various "buttons" are available to mount onto the center of the secondary mirror. These are used to absorb or reflect any thermal emission or reflections from structures nearly on-axis, such as the tertiary support and the aft end of the hydrostatic-bearing tunnel. The two buttons that are avail-

able from the SSMOC have ~ 90 mm diameters; one is a reflecting cone, the other a flat Ball IR Black button.

It is the responsibility of the Principal Investigator for each SI to specify a preferred choice of Secondary Mirror and secondary button to the SSMOC "Point of Contact" for that PI's flight series. It is expected that only one configuration of SM and SM button will be used for a particular flight series.

1.3.1.3 - Telescope Tertiary Mirror Assembly (TMA)

Two slightly different configurations of the telescope optical path are available:

- Nasmyth-1: Dichroic tertiary reflects infrared radiation down the Nasmyth tube, while optical radiation is reflected along a separate yet parallel path to the observatory's Focal-Plane Imager (FPI).
- Nasmyth-2: A fully aluminized tertiary reflects both infrared and optical radiation down the Nasmyth tube.

The fully aluminized tertiary mirror has an aluminum coating of about TBD Angstroms with no protective over-coat.

The Nasmyth-2 configuration is used for Science Instruments that desire a lower telescope emissivity.

Table 1-3. Optical Parameters of the Tertiary Mirror

Optical Parameter	Value	Mechanical Parameter	Value
Free Optical Diameter	440 x 310 mm	Dimensions	498 x 354 mm
Surface Roughness	2 nm (TBD)	Material	Herasil (fused silica)
Wavefront Error	80 nm rms (TBC)	Thickness (3.5 arcmin wedge)	~45 mm (TBC)
Reflective Coating	SAGEM Proprietary dichroic	Weight	11 kg (TBC)
Reflectance $(\lambda\ 0.5\ \mu\ m)$ $(\lambda\ 100\ \mu\ m)$	 0.4 (TBV) 0.99 (TBV)	Thermal Time Constant	~15 minutes (TBD)
FIR Emissivity	0.1 (TBV)	Optical Surface center position (mm)	U = -2502.4 V = 0 W = +86.4
			SOF-SPE-KT-1000.0.03

Dichroic tertiary: The first tertiary mirror carries a dichroic coating, to allow visible light ($\lambda < 1$ μ m) to be separated out for the facility Focal Plane Imager (FPI). Since it is tilted 45°, it has an elliptical perimeter. The reflecting surface is oversized by 20%, to deflect the extended wings of the spatial response of far-infrared focal-plane instruments upward toward the sky, rather than continuing horizontally to the aft bulkhead. A 2mm diameter alignment mark denotes the proper

chief ray position on the optical surface; this is displaced 3.45 mm from the mirror center. Basic parameters are provided in Table 1-3 for reference.

FPI aluminized tertiary: This mirror is located directly under the IR dichroic tertiary. The size of the tertiary support structure and the size of the passage through the bearing, constrain the second tertiary to being somewhat undersized, with some vignetting (~5%) of the visible light beam.

Table 1-4. Imager Specifications

Optical Parameter	Value	Mechanical Parameter	Value
Free Opt. Diameter*	368 x 290 mm	Dimensions*	373 x 300 mm
Surface Roughness	2 nm (TBD)	Material	Zerodur
Wavefront Error	80 nm rms (TBD)	Weight	7.5 kg
Reflective Coating	Protected Ag (TBC)	Thermal time constant	~15 minutes (TBD)
Reflectance: *(λ 0.5 μ m)* *(λ 100 μ m):*	 0.1 (TBV) 0.99 (TBV)	Optical surface center position (mm)	U = -2514.2 V = 0 W = -191.0
FIR Emissivity:	0.1 (TBV)		
*Major axis of ellipse is truncated at upper end by 46.6 mm			

SOF-SPE-KT-1000.0.03; SOF-SPE-KT-1300.0.02

Figure 1-9. IR and Visible Tertiaries in their Support Tower

The 20% oversized uncoated IR dichroic tertiary is on top, and the smaller aluminized tertiary for the FPI is underneath, inside the tertiary tower.

The Nasymth tube opening, on the forward side of the pressure bulkhead, contains no filter wheel, but does provide a mounting surface for fixed pressure window. The investigator if needed may provide special pressure windows. The interface specifications are provided in ICD TA_SI_02 and are discussed further in Chapter 2, “SOFIA Science Instrument ICDs” on page 2-1.

1.3.1.4 - Telescope Imagers

With the dichroic tertiary mirror in place, the observatory’s Focal-Plane Imager (FPI) views nearly the same field of view as the science instrument and can be used for set-up and pointing. With a fully reflective tertiary mirror, the FPI can no longer receive visible light from the telescope. In this case, pointing setup and position control can be performed using the Fine Field Imager (FFI). In addition, a science instrument can provide updates to the telescope pointing using the standard SOFIA command line interface commands discussed elsewhere in this manual (Chapter 2, Section TBD) and may provide their own optical or infrared guide camera. Table 1-6 provides various parameters of interest for the FPI, FFI and the Wide Field Imager (WFI). The latter is used primarily for field recognition by the Mission Control Sub-system (MCS).

The three imagers use the same model Proscan “High Speed Slow-Scan” camera, containing the Thomson 7888A frame transfer CCD. The basic nominal properties of this CCD include the following:

Table 1-5. Nominal Properties of the Thomson 7888 A Frame Transfer CCD

Parameter	Value or Range	Notes
Array Dimensions	1024 x 1024 image area	frame transfer readout
Pixel Size	14 microns	
Binning Options	1x1, 2x2, 4x4	4x4 done off chip
Integration Time	10 – 10,000 ms	
Data Format	14-bit or 8-bit	2 MHz or 5 MHz rate
Maximum Frame Rate	8 frames / s	2x2 binning, 5 MHz
Peak Q. E.	18% at λ 550 nm	Electronic shutter, fill factor
Read Noise	60 e = 5 DN	
Dark current (25 °C):	12500 e-/s	No FPI cooling, CCD ~at cabin temperature in flight
Dark current (-20 °C):	200 e-/s	Likely for WFI, FFI

Table 1-6. FPI, FFI, and WFI Parameters

Parameter	FPI	FFI	WFI	Notes
Optics Description	Cass TA + 8x reduction	Schmidt-Cass + field expander	F/2 Petzval lens	FPI has ±60 cm focus range, reticle, reimaging optics
Aperture Diameter	2500 mm	254 mm	68 mm	
EFL	6176 mm	733 mm	136.5 mm	TRP-KT-5100.0.04 Annex B
FOV	8’ x 8’	67’ x 67’	6.0° x 6.0°	TRP-KT-5100.0.04 Annex B
Image Scale (arc— sec/pixel)	0.47 ”/pxl	4.1 ”/pxl	21 ”/pxl	FPI scale varies 10% over focus range
Star Image Size (80% CED)	7 ”	13 ”	75 ”	FPI seeing-limited; FFI, WFI optics limited
Sensitivity (S/N = 10 in 1 s)	15	13	11	TN EWD 007 TN EWD 008
Centroid Precision (S/N = 10)	~0.05 ”	~1 ”	~8 ”	TN EWD 007 TN EWD 008
Filters Available	• 3 ND’s • red (day) • clear • blankoff	• 3 ND’s • red (day) • clear • blankoff	• 3 ND’s • red (day) • clear • blankoff	“red” = Schott RG1000 (λ > 900 nm)

The table reflects some of the basic optical and performance parameters for each of the three imagers.

1.3.1.5 - Science Instrument Interface

Figure 1-10 shows where the Science Instrument (SI) will be mounted to the telescope, on the cabin side of the pressure bulkhead. This is called the SI Mounting Flange and it has a diameter of 1041.4 mm (41 inches). The IR beam lies along the axis of this flange.

Surrounding the SI Mounting Flange is the Counterweight Plate Assembly or "Balance Sub-Assembly"(BSA). Some SI equipment can be mounted to this Sub-Assembly using a Counter-weight Rack (CWR). Part of an empty CWR is visible in Figure 1-10, at the very top of the BSA.

SOFIA allows various instrument mounting configurations. Every instrument configuration must have a demonstrated pressure boundary seal, since when the Nasmyth tube gate-valve is open (required to observe) the SI configuration is part of the pressure barrier between the cabin and cavity.

The maximum weight permitted for a science instrument and its electronics mounted to the SI Mounting Flange or Counterweight Assembly depends upon the location of the SI's and its equip-ment's center of mass with respect to the hydrostatic-bearing fulcrum (see Chapter 2, "SOFIA Science Instrument ICDs" on page 2-1 for details). After installation of the SI, the telescope is balanced by a proper distribution of counter weights on the BSA. The telescope assembly must be well balanced about all three axes of motion provided by the spherical hydrostatic-bearing. The balancing procedure is performed by SOFIA staff and may require several hours for a new SI. Small changes in balance (e.g. cryogenic depletion) are automatically compensated for by motor-driven counterweights during observing.

Permanent cabling to the science instrument and the secondary mirror controllers are accessible through patch panels located forward of the telescope. Additional lines run to a second patch panel mounted on the forward portside of the aircraft's pressure bulkhead. A single cable drape connects the two patch panels and eliminates the need for the free-hanging cables. All science instrument interfaces to the observatory are discussed in Chapter 2 of this document.

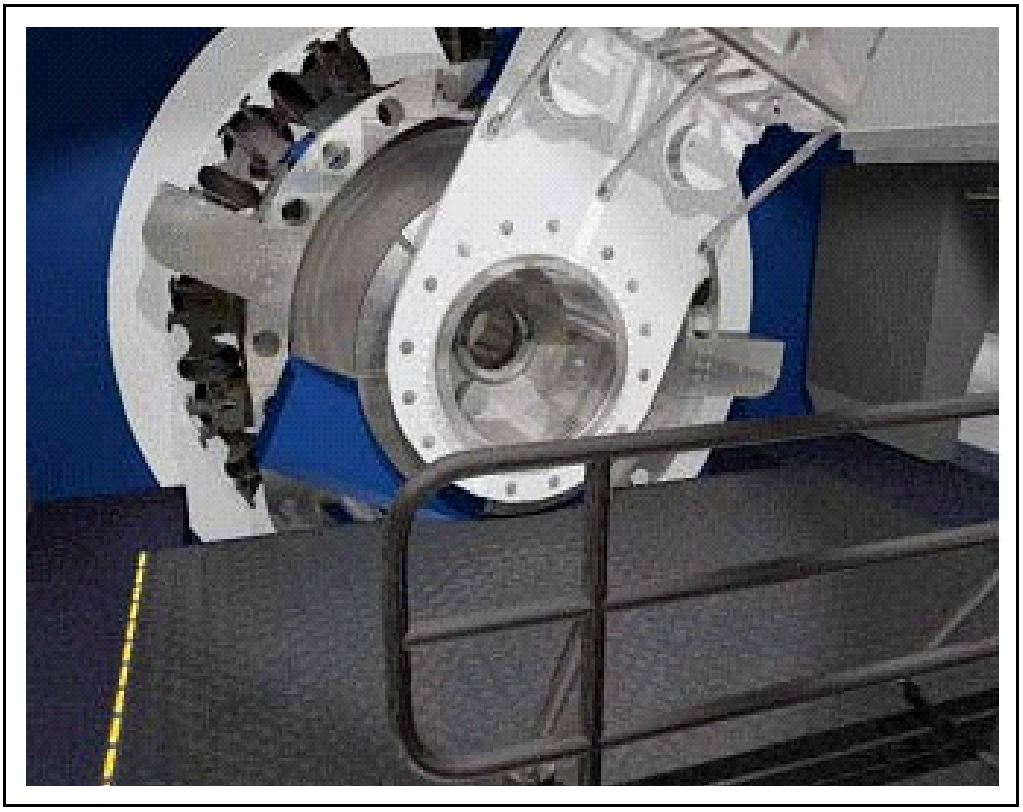

Figure 1-10. SI Mounting Flange of Telescope Assembly (no SI installed)

1.3.2 - Telescope Pointing and Control

During taxi, takeoff, and ascent, the telescope is “caged” (i.e., fixed with respect to the bulkhead) and “braked” with respect to the inner-cradle. About five to ten minutes before observing is to begin, the observatory staff begins activating the telescope stabilization system and “uncages” the telescope. The telescope must remain braked (i.e., locked into position with respect to the inner-cradle) until the aircraft is on heading to observe, and this is also the case every time the aircraft turns to go onto a new heading for a new observing leg.

The telescope aperture door is normally kept closed until the aircraft is at 35,000 feet or higher. After the flight crew has leveled off the aircraft at the initial assigned altitude, the door is raised to expose the telescope. Opening the door takes about two minutes (TBV). After the In-flight Director (IFD) receives verification from the flight deck that the aircraft will remain level and is on the correct heading, the Telescope Operator may un-brake the telescope and begin actively slewing or pointing the telescope. The Telescope Operator or the Investigator will then have control of the telescope for fine pointing. However, the IFD may override telescope control at any time.

The SI team can control the telescope through Mission Control GUIs or through command lines issued from an SI computer or PI Console or commands downloaded to the Mission Control Sub-

system (MCS) through XML files. The observing modes supported by the SOFIA Mission Control System are detailed in Chapter 4 of this book.

Several sub-systems and procedures are involved in providing the stability and precise pointing ability of the telescope. These may be described as five stages of increasing precision and stability. The five stages are:

1. The Aircraft Autopilot — See 1.3.2.1 - ”The Aircraft Autopilot” on page 1-22
2. Vibration Isolation — See 1.3.2.2 - ”Vibration Isolation” on page 1-22
3. Spherical Hydrostatic-bearing — See 1.3.2.3 - ”Spherical Hydrostatic-bearing” on page 1-23
4. Gyros and torque motors — See 1.3.2.4 - ”Gyros and Torque Motors for Three Axes” on page 1-23
5. Imager Star Tracker — See 1.3.2.5 - ”Imager Star Tracker” on page 1-24

The fine pointing stability is set by the gyro-torque motor control system; and the fine pointing accuracy (precision) is set by gyro updates from the imager star tracker system.

1.3.2.1 - The Aircraft Autopilot

The first stage provides the attitude and heading stability of the 747SP aircraft. To prepare for observing an object which has initial azimuth A, the Pilot turns the aircraft onto a true heading of A + 90°, placing the object within the +/- 3° azimuth range of the telescope mounting. During the observing leg, the Mission Control Sub-system (MCS) software uses Universal Time, the object’s coordinates, and the aircraft’s actual position and attitude to repeatedly calculate the object’s present local azimuth and command the corresponding heading via the autopilot. For safety reasons, the aircraft heading is *not* automatically adjusted if the telescope is moved away from the position of the object scheduled for the current leg.

By fine-tuning the autopilot for the current aircraft altitude, airspeed and weight, excursions in roll are limited to +/- 0.5 (TBV) degrees. The autopilot can limit roll in light turbulence to +/- 2 (TBV) degrees. In normal conditions, aircraft pitch and yaw fluctuations are limited to less than one degree. The telescope is isolated from these attitude variations by stages three and four described below.

1.3.2.2 - Vibration Isolation

The second stage consists of a series of pneumatic vibration isolators. These are mounted within the forward pressure bulkhead of the telescope cavity in a horizontal plane containing the center-of-mass of the telescope assembly. When activated, they isolate the telescope system from some of the aircraft translational vibrations, assuming light to moderate turbulence, passed to the telescope through the bulkhead. In such conditions, the telescope assembly may exhibit motions of up to an inch with respect to the cabin, primarily in the vertical direction. However, the inertia of

the telescope assembly is significant, and this exhibited motion is really the aircraft moving with respect to the telescope assembly.

1.3.2.3 - Spherical Hydrostatic-bearing

The third stage is the hydrostatic-bearing, which floats on a thin film of compressed oil that is filtered and re-circulated. The gap between the spherical bearing and its housing is 50 microns (2 mils). The spherical shape of the bearing active surfaces provides rotational isolation of the telescope from the aircraft, and permits pointing stabilization or controlled motions with respect to three orthogonal axes. Actual telescope pointing control is provided by stages four and five.

1.3.2.4 - Gyros and Torque Motors for Three Axes

Stage four consists of three rate-integrating fiber-optic gyroscopes and three DC segmented torque motors. Each gyro/torquer control loop operates on one of the three orthogonal axes: cross elevation (XEL), elevation (EL), and line-of-sight (LOS). Note that this is not a true alt-azimuth arrangement: the XEL axis actually tilts back from the zenith by an angle equal to the telescope elevation angle (20° – 60°), as shown in Figure 1-11.

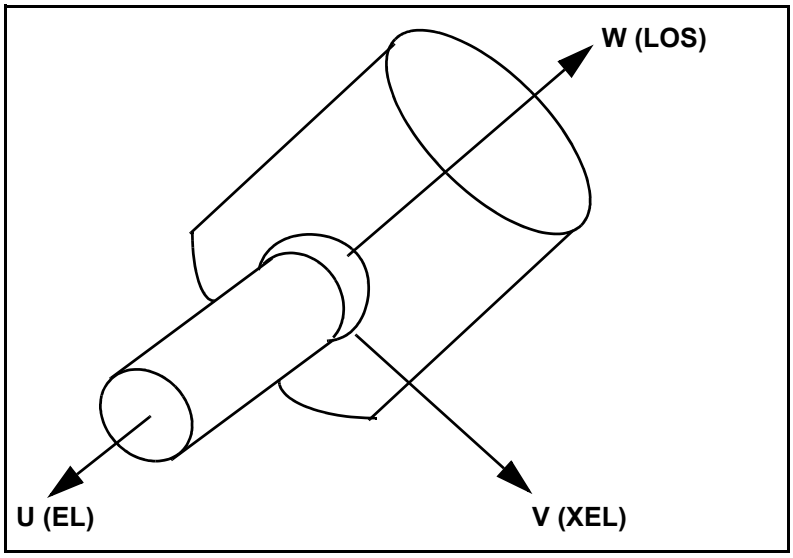

Figure 1-11. Telescope Control Axes

The telescope, hydrostatic-bearing and Nasmyth Tube are shown schematically at a typical elevation angle. Movement over the 40° elevation range is a rotation about the U axis, also called EL. The other orthogonal axes are the V "cross-elevation" axis, also called XEL, and the W "line-of-sight" axis, also called LOS.

To avoid static friction, the telescope motors are not mechanically coupled to the telescope. Torques are applied by varying the magnetic fields of stator coils attached to the telescope assem-

bly's inner cradle. The stator fields react against the fixed fields of permanent magnets mounted on a rotor ring attached to the hydrostatic-bearing/Nasmyth tube. The stator currents are modulated by error signals from their corresponding gyros, which are mounted on the telescope near the bearing. To permit slewing the telescope, manual control of the torque motors is available at the Telescope Control Console. The maximum slew rate is 1 degree per second. Large elevation changes require rotation of the inner-cradle with respect to the outer-cradle of the telescope Assembly by the Coarse Drive system, which is a direct mechanical drive.

1.3.2.5 - Imager Star Tracker

The fifth stage is represented by the imager tracking system consisting of three imagers, their associated optics, and digital processing electronics. The system uses the digitized video image of a star to obtain relative pointing information at a few Hz with arc-second angular resolution. Error signals generated by the tracking computer are fed into the gyro-torquer control loops. Typical tracking accuracy using the FPI is about 0.5 arc-second for stars brighter than about visual magnitude 15 (TBV). Slightly fainter stars may be used with longer FPI integration times, but with slightly degraded pointing accuracy. The FFI provides a field of view of 70 arc-minutes, with a visibility limit of V = 13 with a one-second exposure. Offset tracking is possible for any star in the field brighter than V = 13 with a similar exposure time. Further details on the tracking system are given later in this section.

1.3.2.6 - Rotation Angle

As in all alt-azimuth systems, rotation of the sky image occurs in the focal-planes of the telescope and the attached cameras. The orientation of the sky around an object being observed as measured in the telescope focal-plane is defined by a Rotation Angle or Rotation of the Field (ROF).

The SOFIA Rotation Angle is similar to the Parallactic Angle, which is formed by great circle arcs from the object to the zenith and to the north celestial pole. However, on SOFIA the Rotation Angle (i.e., ROF) is measured clockwise from the "up" direction in the focal plane to the north celestial pole, as shown in Figure 1-12. "Up" is the same for all imagers on SOFIA, and is the

direction the line-of-sight of the telescope (W-axis) would move on the sky with a right-hand rotation about the U-axis of the telescope (see Figure 1-11).

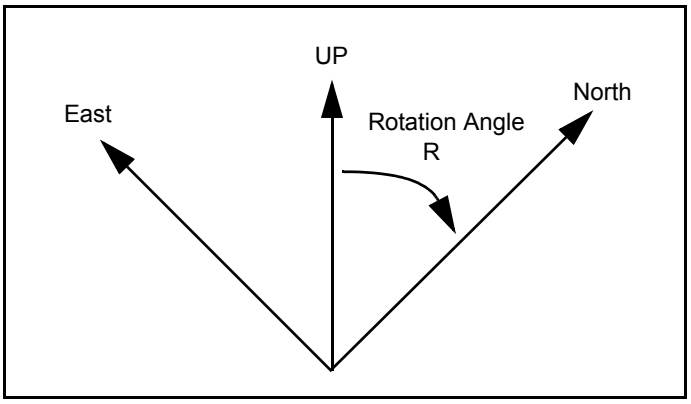

Figure 1-12. The Sense of the Rotation Angle

Expected values of the Rotation Angle are listed on the final flight plan. Depending on aircraft heading and object elevation angle, the rotation angle may not change at all, or may change at rates as high as 70° per hour. In flight, the local vertical of the telescope body may not pass through the zenith, due to LOS motions and aircraft attitude fluctuations. The current Rotation Angle, corrected for LOS angle, aircraft pitch and heading error, is provided in MCS house-keeping.

1.3.2.7 - Line-of-Sight and Azimuth Resets

The telescope Line-of-Sight (LOS) position may be controlled in several ways. The default is the "freeze mode", in which the telescope is inertially stabilized about the LOS axis, resulting in a constant rotation angle for a limited time interval. When the telescope approaches a limit of LOS motion (3° from center), it must be slewed back to the other limit before the freeze mode can be resumed. This "LOS rewind" takes about ten seconds, and the time interval between rewinds may be anywhere from about 10 minutes to over an hour depending upon heading and elevation. The science team can specify how far from the LOS limit they should receive a warning of approaching need for a reset. In this way the rewinds can be coordinated with natural pauses in observation data taking. This allows a modified version of the freeze mode, where a smaller LOS deviation is set as the limit, and LOS rewinds are performed more frequently.

The telescope will lose stability if it moves more than 3° from center in azimuth. This may occur while slewing, in turbulence, or if the aircraft develops a large heading error. The SOFIA flight-planning software calculates the required aircraft heading for a particular flight-leg based on a centered telescope in azimuth and the location on the sky (at a given UT date/time) of the object being observed on that flight-leg. The flight-planning software then translates this to a ground track (required information for Air Traffic Control). If winds aloft are different from those predicted, then the ground track will differ for a given aircraft heading. This is called a ground head-

ing error, and usually has to be corrected, either by instigating a slight aircraft heading deviation (making the TA not centered in Azimuth) or a short "dead-leg" to get back on track. No observations are carried out on dead-legs.

The Telescope Operator may also find it necessary on occasion to "center up" the telescope. This action mechanically settles the telescope into the centers of the range of the torque motors. Centering takes about ten (TBV) seconds, after which the telescope may be un-caged to resume observing.

1.3.3 - Observatory Optical Performance

Based on the optical data in Table 1-3 through Table 1-6, the assembled SOFIA Cassegrain telescope should be capable of producing a 1.0 (TBV) arc-second 80% encircled energy diameter image of a visual point source.

1.3.3.1 - Focal Plane Image Quality

In January 2005, Dunham et al obtained a series of CCD images of stars with very short exposure times under a variety of flight conditions (Report SOF-XXXX). These star images had long-exposure FWHM sizes of about 3 arc-seconds (TBV). The large size of the airborne image is presently believed to be due to contributions from the shear layer, air temperature variations in the cavity, and image jitter caused by vibration and dynamic flexure of the telescope structure. The shear-layer seeing becomes unimportant for wavelengths longer than 5 microns. FLITECAM star images at 5 microns are on the order of 1.5 arcsecs FWHM (TBV). Preliminary analysis implies the telescope provides diffraction-limited imaging at infrared wavelengths longer than about 15 (TBV) microns. As a rule-of-thumb, where SOFIA is diffraction limited:

$$\Theta = 1 \text{ arc-second } (\lambda/10 \text{ microns})$$

1.3.3.1.1 - Range of focus

The secondary mirror positional adjustment provides focus over the range U = +/- 600 mm (where the U-axis is illustrated in Figure 1-11). The secondary mirror is made of silicon-carbide with a diameter of 352 mm, which is larger than the chopping mechanism housing, but slightly undersized with respect to the f/1.2 light cone of the primary mirror.

Table 1-7. Examples of Focal-Plane Positions

Focus Setting	Focal-plane Position*	Image Scale	f-ratio	Notes
+2760 µm	300 mm aft	4.6"/mm	f/18	aft limit
+1320 µm	0 mm aft	4.4"/mm	f/18.8	at SI flange
0 µm	300 mm fwd	4.2"/mm	f/19.5	nominal
-1220 µm	600 mm fwd	4.0"/mm	f/20.5	

Table 1-7. Examples of Focal-Plane Positions

Focus Setting	Focal-plane Position*	Image Scale	f-ratio	Notes
-2340 µm	900 mm fwd	3.9"/mm	f/21	fwd limit
**Reference position is at the Nasmyth SI mounting flange.*				

Some examples of focal-plane positions and associated values are given in Table 1-7. More detailed tables of back-focus location, f-ratio, scale, etc. for both secondary mirrors are given in Appendix D.

1.3.3.1.2 - Variations in telescope focus

A small shift of focus is known to occur between ground-based warm telescope conditions and in-flight cold telescope conditions. This is normally corrected by adjusting the focus early in the flight while observing a star image in the focal-plane video monitor. The amount of adjustment has been typically a decrease of about TBD mm (TBV) in the focus. As the telescope cools to the ambient temperature at 41,000, changes in the telescope's focus are expected. Such variations during a flight are reduced since the telescope cavity is pre-cooled to stratospheric temperatures before a flight.

1.3.3.2 - Chopping Secondary Mirror Performance

The oscillating secondary system provides stationary or chopped images at frequencies of 0.5 to 20 Hz. An external drive input permits phase control by the SI. The chopping amplitude may be set as high as 10 arc-minutes on the sky; however, the tilt of the secondary mirror produces coma as large as about an arc-minute at the maximum 10 arc-minute amplitude. An offset control can be used to tilt the chopping motion away from symmetry about the optical axis. However, if the tilt-controller mechanism (TCM) is used to create an offset, the maximum chop amplitude available is reduced by twice the offset:

$$\textit{Maximum chop amplitude} = (10 \text{ arc-minutes}) - 2 \times \textit{offset} \text{ (TBV)}$$

The chop direction with respect to azimuth may be changed in flight through a range of 180°. If chopping needs to be set at a particular position angle P with respect to North on the sky for rotation angle R, the chopping angle O with respect to azimuth would be set to:

$$O = P + 90 \text{ degrees} - R \text{ (If } O < 0, \text{ add } 180 \text{ degrees)} \text{ (TBV)}$$

The efficiency of the oscillating secondary motion is shown in Figure 1-13. The waveforms were recorded from the position transducers used by the chopping control feedback loop.

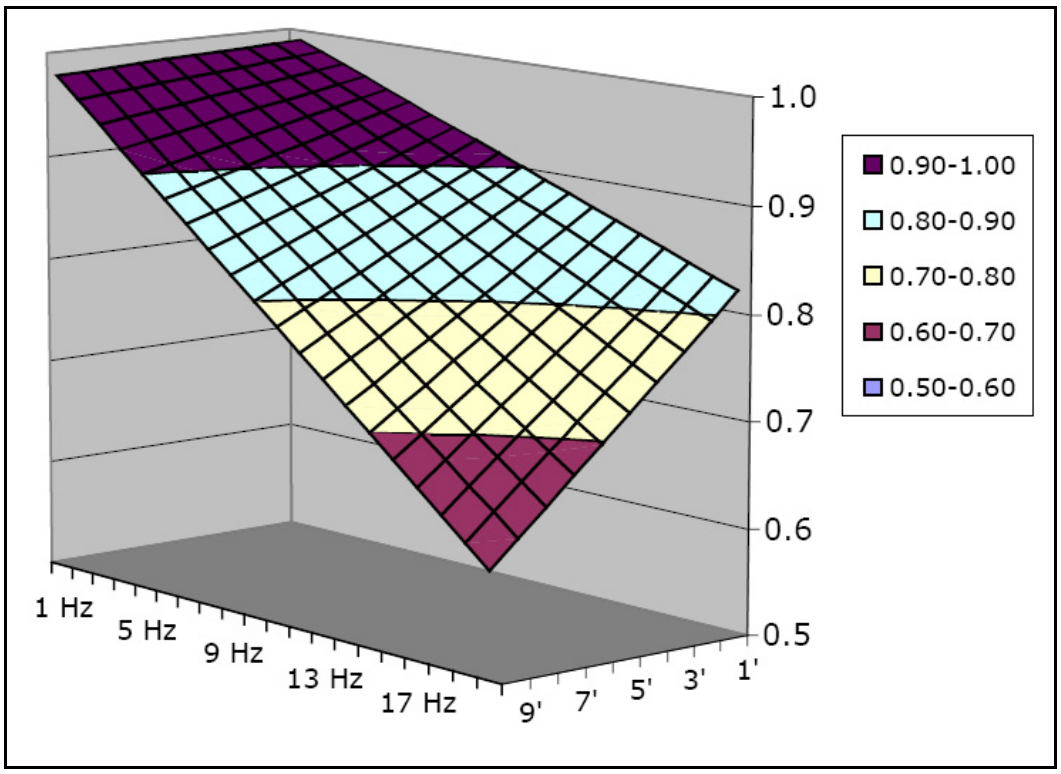

Figure 1-13. Efficiency of Chopping Secondary Mirror

A plot of duty cycle versus chop frequency (Hz) and throw (arc-minutes). This is based on rise times of 4 to 10 ms measured during early bench tests at room temperature in 2002.

"Efficiency" is the percentage of the time that the position transducer waveform was within 10 arc-seconds of either end of the motion. (TBV)

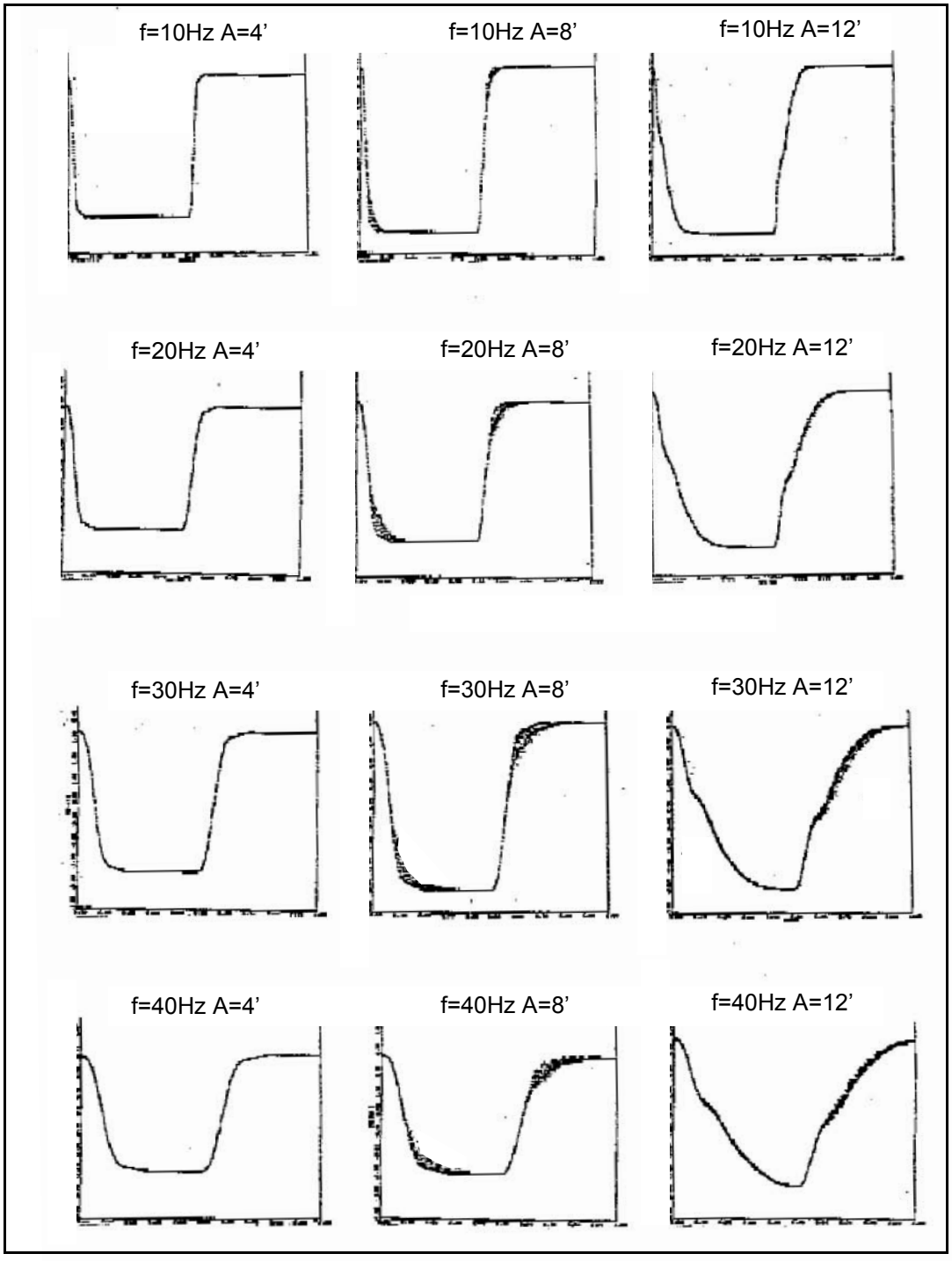

Figure 1-14. SMA Position Waveforms at Selected Frequencies & Amplitudes

1.4 - Mission Control Sub-System

The Mission Control and Communications System (MCCS) is comprised of two major sub-systems: the Mission Controls Subsystem (MCS) and the Observatory Support Subsystem (OSS). OSS basically consists of the Power Distribution System (PDS), the Mission Audio Distribution System (MADS), Video Distribution System (VDS), and Water Vapor Monitor (WVM) – which will be discussed below in section 1.5 - ”Other Observatory Sub-Systems” on page 1-32.

The MCS, however, is the major portion of the MCCS operation, providing the majority of operator supervisory control and monitoring of the observatory, especially the TA. The MCS will provide the majority of intersystem communications and facility control and monitoring via a LAN. The MCS will also provide other ancillary functions, including storage and retrieval of data, printing and plotting functions, computations, and intersystem data file transfers. The MCS equipment includes servers, mission support computers, and operator consoles.

The MCS will provide a suite of computer workstations and servers. The design concept will use a UNIX workstation at each MCS console with each connected to three UNIX servers by the LAN. The standard features of the UNIX operating system allow peripherals such as disk and tape drives, printers and modems to be accessible from any workstation on the LAN and allow a system administrator to assign privileges to those resources. The servers and workstations will execute software applications and provide access to high-capacity disk and tape storage drives. Any observatory workstation will be able to print to any of the printers located in easily accessible areas of the cabin. This approach allows for reconfigurable workstations and provides reliability through redundancy.

Housekeeping functions will prevent data loss and ensure timely return of the most current information for all requests for facility data. Time tagging and synchronization is required on the observatory, and an IRIG-B timing distribution system accurate to at least 1 ms will be provided.

The LAN will provide internet access via ground umbilical cable connections to the N211 Hangar and support facilities at NASA ARC when the Observatory is in the N211 hangar or near the hangar on the ramp area.

Figure 1-14 gives an overview look at the MCS communications architecture. The SI computer system communicate for the most part through the MCS network switch (via the PI Patch Panel – see MCCS_SI_02) with two exceptions:

1. The Secondary Mirror Controller (SMC) has a direct interface to the SI, and this physical and functional link is described in the ICD TA_SI_04 (Chapter 2, “SOFIA Science Instrument ICDs” on page 2-1);
2. The SI can down load directly the WFI, FFI, and FPI digital images and store for SI housekeeping. The Observatory at ORR will only store such images in digital video format. Particular frames of any image from the WFI, FFI, or FPI can be requested to be “logged” in a FITS

file, but storing a continuous stream of such data is the responsibility of the SI team through this direct link. See MCCS_SI_02 (i.e., Chapter 2) in regards to the PI Patch Panel.

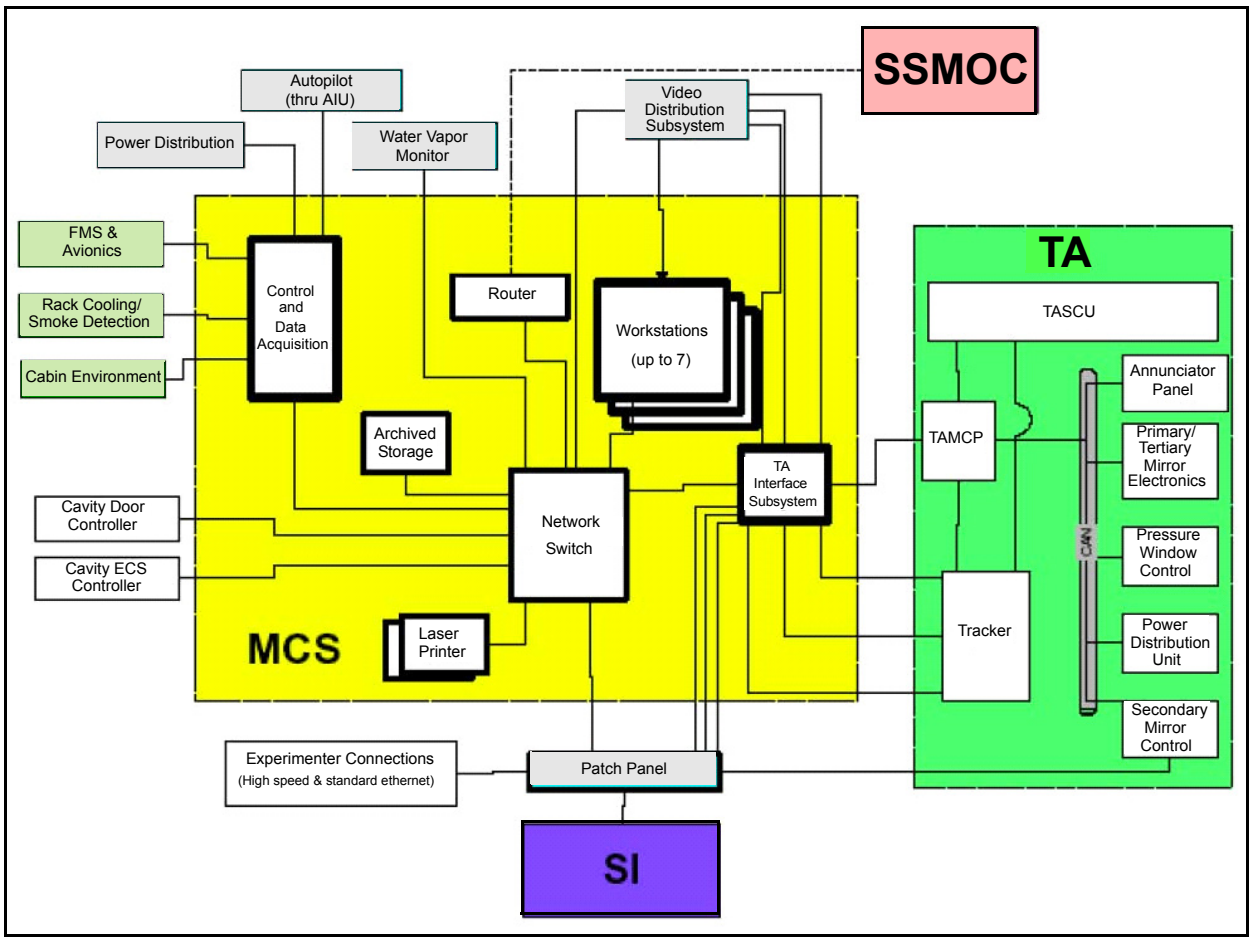

Figure 1-15. MCS Communication Architecture

The TA box in Figure 1-15 shows four important control sub-systems:

1. **TAMCP** (TA Master Computer Processor): This sub-system is the communications hub, and passes transmissions in correct sequence to and from the other three TA control sub-systems below, and the MCS.
2. **TASCU** (TA Servo Control Unit): This sub-system is at the heart of the telescope's pointing and control. All commands to move the TA or change state of the TA are issued from here. In particular, this is the sub-system that runs the gyro servo control loop that inertially stabilizes the TA pointing to the sky.
3. **Tracker**: This sub-system visually monitors the sky (using one or more of the three images FPI, FFI, and WFI) to correct the gyro servo system for slow gyro drifts or other inaccuracies. The Tracker do not move the TA, it sends information to the TASCU (via the TAMCP) so the TASCU can make the physical correction (see section 1.3.2.5 - "Imager Star Tracker" on page 1-24 for more on the Tracker process).

4. **SMCU** (Secondary Mirror Control Unit): This sub-system controls the Focus Centering Mechanism (FCM) and Tip/tilt Chopping Mechanism (TCM) of the Secondary Mirror Assembly (SMA). The observer can communicate to it through the MCS, which talks to it through the TAMCP. The observer can also communicate directly to the SMCU in limited ways through the direct SI to SMA link as described in the ICD TA_SI_04.

1.5 - Other Observatory Sub-Systems

The SOFIA observatory requires a host of additional hardware for successful operations both in the air and on the ground. A number of these subsystems are described below.

1.5.1 - Cavity Door System (CDS)

The Cavity Door System was developed to maintain the telescope cavity aero-acoustic environment within limits, to minimize the impact of an open telescope cavity upon aircraft performance and to track position commands from the MCS so-as to maintain TA and Cavity Door Aperture alignment. The major components consist of:

- Upper Rigid Door (URD)
- Aperture Assembly and Lower Flexible Door (LFD)
- Fairings
- Cavity Door Drive System (CDDS)
- RD Seal System

1.5.1.1 - Aperture Door Assembly

The URD, LFD, and Aperture Assembly (AA) are capable of smooth operation within their full ranges of motion on the ground and under operational load conditions specified at altitudes of 35,000 feet and above. The normal operating envelope of the observatory with the door open will be between 35,000 and 45,000 ft. and at or below the maximum operating airspeed of Mach no. 0.87 (TBV). The structure will be substantiated to allow continued safe flight, with restricted operational limitations, in the event the door does not close after use above 35,000 ft. such that the airplane can be landed safely.

1.5.1.2 - Cavity Door Control

This Cavity Door Drive System (CDDS) controls the operation of the URD and aperture / LFD assemblies and the URD seal. When the URD is in the closed position, the CDCS inflates the seal. Prior to opening the URD, the CDCS sends commands to deflate the seal. The URD drive operates independently of the aperture assembly drive. The MCS provides command inputs to the CDCS to indicate desired position for the aperture assembly to track the telescope. In the event the

upper rigid door assembly or aperture assembly binds, or the AA/LFD exceeds velocity limits, the control system will remove power from the cavity door system drive motors and apply the brakes.

1.5.1.3 - Cavity Door Data

The MCS determines the desired position for the Aperture Assembly needed to prevent eclipsing the telescope field of view. The MCS transmits the desired aperture position setpoint to the CDDS. The CDDS compares the new setpoint with the actual aperture position, and moves the aperture accordingly. The CDDS drives the URD correspondingly with the aperture, to maintain a precise URD position relative to the upper edge of the aperture assembly, ensuring no gap develops between the two assemblies.

1.5.2 - Cavity Environmental Control System (CECS)

The CECS is used to pre-condition the telescope and telescope cavity for exposure to the stratosphere, where the ambient air temperature is about -50 º to -60 º Celsius. A "precool" procedure is executed, starting five hours (TBV) before scheduled takeoff, to lower the temperature of the SOFIA telescope cavity, thereby reducing the temperature difference between the optical surfaces and the recovery air at altitude. "Recovery air" is the air from the stratosphere that is swept into the cavity. It has been kinetically warmed so the cavity needs only to be cooled to approximately – 30 to – 40º Celsius instead of – 50 to –60º Celsius.

At least five hours before takeoff, the telescope cavity is inspected and sealed, and then purged of moist air by continuous blowing of dry nitrogen gas into the cavity. The nitrogen gas is obtained from dewars of liquid nitrogen on the ground. During the precool, these liquid nitrogen ground dewars are connected to the telescope cavity through ports in the aircraft fuselage. After the nitrogen purge has lowered the cavity dewpoint, the cooling process begins. The PCU cools the cavity air using a liquid nitrogen purge. An in-situ ventilation system recirculates the air and removes any ambient water vapor thus preventing condensation on the SOFIA telescope optics. The ground dewars are disconnected about 30 minutes before takeoff. At this time the telescope primary mirror is usually at about -30 º Celsius. Nitrogen flow into the telescope cavity is maintained through takeoff with on-board liquid nitrogen dewars, until the aircraft is above 25,000. After observing is concluded and the door is closed, a desiccant dryer connected to the air-conditioning system of the aircraft purges the cavity with warm dry air, and maintains an overpressure during descent, landing, and cavity warm-up on the ground to prevent water condensation on the telescope optics.

The warm-up period for the cavity usually is 2 to 3 hours in duration, some of which is occurring during descent. When the primary mirror temperature has risen above outside ambient dew point, access to the cavity is permitted. Without using the heaters, the cavity may be opened about eight hours after landing.

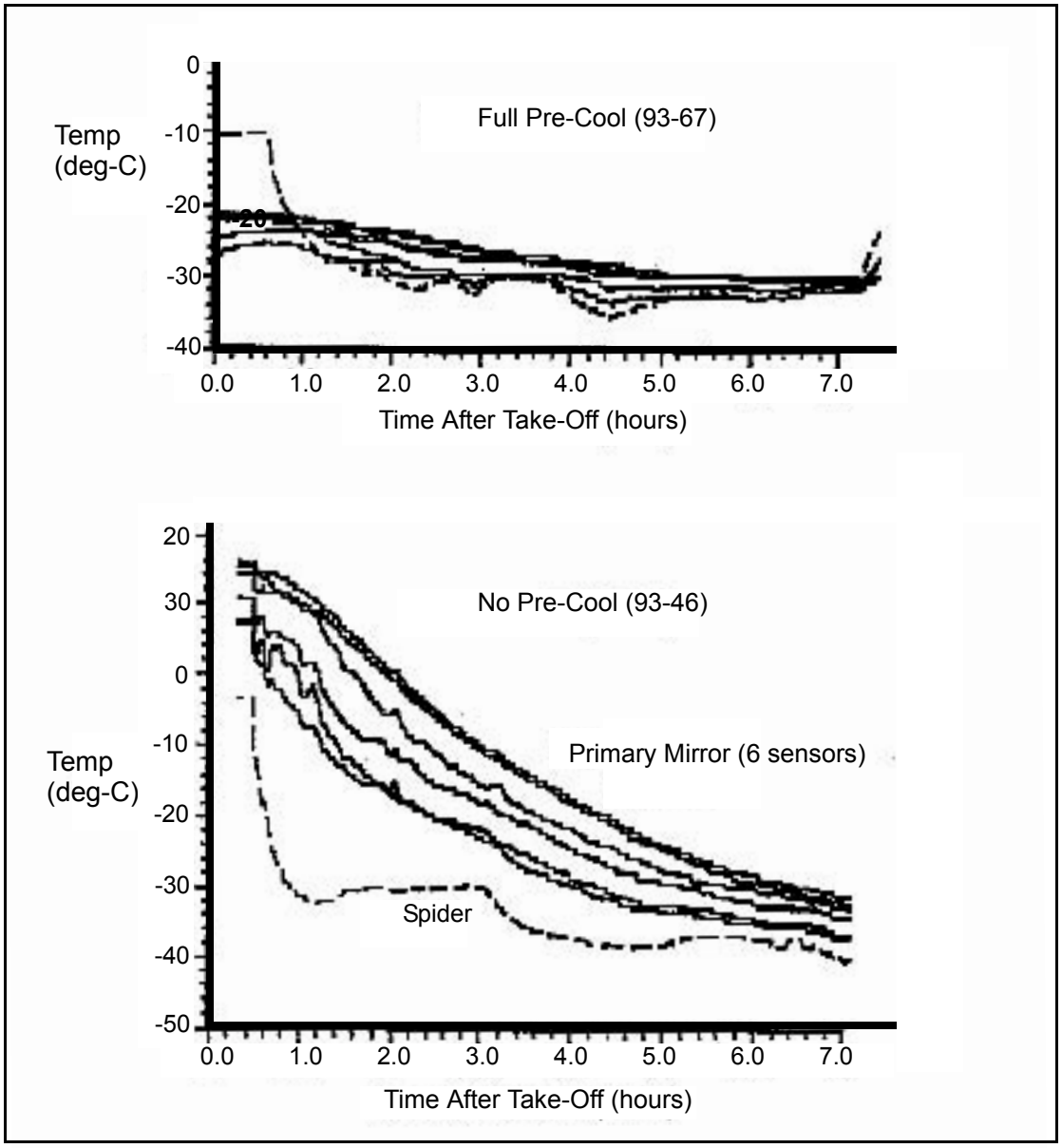

Figure 1-16. Telescope Temperatures with and without Pre-Cool

The six primary mirror temperature sensors are located on the uncoated surfaces of the central hole, the outer side surface, and space radially along the bottom. The dashed line, labeled "Spider" in the lower plot, indicates the temperature of the spider vane in the telescope headring.

1.5.3 - Water Vapor Measurement

The principal purpose for SOFIA is the detection and measurement of far-infrared radiation from celestial objects. Observations throughout most of the infrared are impossible from ground-based

observatories due to absorption by water vapor in the troposphere. Although SOFIA usually flies above the moist troposphere, a measurable amount of water vapor is present in the stratosphere at densities of approximately 2 to 10 parts per million. This residual water vapor over burden is sufficient to have a noticeable affect on most far-infrared observations (e.g. broadband photometry or spectroscopy of lines blended with strong water vapor absorption lines).

1.5.3.1 - Variations in Overburden

The water vapor burden at altitude for use in the calibration is affected by the season, latitude, the jet stream, and somewhat by local weather conditions at lower altitudes. In general, the tropopause is higher in the local summer, and higher water vapor burdens may be encountered. This is also true in the tropics throughout the year. In temperate latitudes, the zenith water vapor overburden at observing altitudes is typically 5 to 15 μm, but may exceed 20 μm if the aircraft is not above the tropopause. At 41,000 feet or higher, the WV overburden occasionally drops below 5 μm. The distribution of stratospheric water vapor can be quite variable, and the observed zenith burden may change as much as a factor of three on time scales as short as 15 minutes. During flight, the current observed water vapor value appears in the housekeeping video display, updated every 15 seconds. These measurements are also available after each flight, as plots from the housekeeping data file for the flight.

1.5.3.2 - Radiometer Design

Atmospheric water vapor measurements will be obtained with an infrared radiometry system developed by Dr. Thomas Roellig (NASA/ARC). The sensor is a heterodyne mixer configured for the measurement of the 183 GHz rotational line of water. The Water Vapor Monitor (WVM) is mounted at a fixed elevation of 40° in the upper deck of the aircraft. The WVM is responsible for measuring the integrated water vapor at 40 degrees, while the SOFIA aircraft is at normal operational altitudes. These data are used to correct the astronomical infrared data obtained by the telescope and will also be used in the algorithm that determines successful SOFIA observatory flight hours for contractual purposes. The WVM reports its measured water vapor overburden to the aircraft Mission Controls and Communication System (MCCS) once every 15 seconds while the SOFIA observatory is in normal operation at altitude.

1.5.3.3 - Principles of Operations

The basic technique compares radiometric measurements of the center and wings of the 183.3 GHz rotational line of water vapor to atmospheric models to infer the WV overburden. Measure the total water vapor burden along a line-of-sight between the WVM and the top of the earth's atmosphere.

Since in practice the aircraft will not be flying perfectly level all the time, the WVM measurements must be corrected for the true aircraft roll and pitch angles during the measurements. The

aircraft roll and pitch angles is provided to the WVM by the aircraft flight system autopilot, which can measure these parameters to better than 0.1°.

The Radiometer Head contains an antenna that views the sky, two calibrated reference targets (one heated and one ambient temperature microwave blackbody), an RF switch, a mixer, a local oscillator, an IF amplifier, and an inclinometer. All of these components are mounted together on a baseplate and are attached to the inner surface of the aircraft fuselage, so that the antenna can observe the sky through a microwave-transparent window. The antenna itself employs a quasi-optical design with a microwave lens that feeds a feed horn. The beam pattern is Gaussian with a full-width-half-maximum diameter of 0.87°. A sub-harmonic mixer mounted directly behind the feed horn mixes the 183.3 GHz radiation down to a bandwidth of 1 GHz with the radiometer operating in double sideband mode. The sub-harmonic mixer is fed by a phase-locked 91.65 GHz local oscillator. The intermediate frequency signal out of the mixer is amplified by an RF amplifier with a bandwidth of 100kHz - 500MHz before it is sent on to the IF Converter Box.

1.5.3.4 - Calibration

Since the WVM operates as a radiometer, accurate gain stability is important. In order to achieve this stability the two reference blackbodies are used to periodically insert a stable signal into the radiometer. Small motors rotate mirrors that direct images of the black body targets into the feed-horn field-of-view once every 5 seconds. One mirror, the Sky/Calibrator Mirror directs the view of the radiometer between the sky and the black body calibrators. The second mirror, the Hot/Ambient Mirror, selects between the hot and ambient temperature black bodies. Therefore, over a 15 second period the radiometer views the sky for 4 seconds, an ambient temperature black body target for 4 seconds, and a heated black body target for 4 seconds. One second is allowed to move the mirrors at each viewing position. The temperatures of the two black body targets are measured with temperature sensors.

1.5.3.5 - Typical Post-flight Results

A typical zenith water vapor plot for a flight is shown in Figure 1-17 below. The plot is usually provided with temperature and altitude data as well.

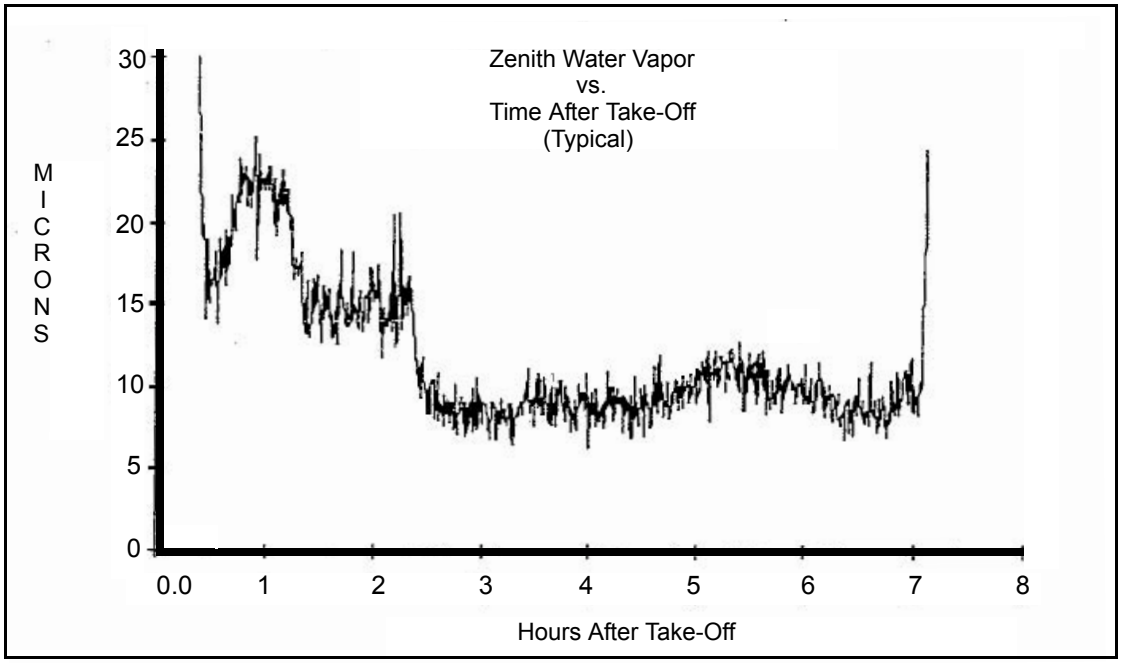

Figure 1-17. Typical Zenith Water Vapor Plot During Flight

1.5.4 - Global Pointing System (GPS)

A TRAK Systems model 8820-2 “GPS Station Clock” is installed in the forward electronics console with an antenna mounted in the overhead sextant port on the flight deck. Accurate time (UTC), position and altitude can be displayed on the unit’s front panel, and this information is also available as MCS housekeeping data. The position and altitude accuracy is quoted as ± 30 m rms. Other outputs available include an “IRIG B” time signal with millisecond accuracy, and pulses at 1 Hz or at 1 MHz. These outputs are routed to the PI patch panel aft of the experimenter’s science instrument rack and can be routed from there to the SI.

1.5.5 - Vacuum Pumping System

There are three independent pumping stations on the Observatory for SI Team use for pre-flight operations and during flight. Two pumping stations are used for pumping on cryogens and one is used for pumping containers (such as the SI Mounting Flange Tub) down to pressures of a few millitorr. The three pumping stations use identical pumps: Leybold Trivac D 40 B oil sealed, two-stage, rotary-vane type, which have a nominal pumping speed of 27.1 cfm (767 Li/min) at the pump, which translates to a pumping speed of 460 Li/min at the SI Mounting Flange on the telescope. Only one pumping station is available for first light observations in January 2005.

Vacuum lines are permanently installed between the pumps and their respective manifolds and gauges, with flexible vacuum tubing providing the interface to the SI on the SI Mounting Flange.

USRA also supplies a 0-800 Hg mm pressure gauge, a 0-50 Hg mm gauge, and a millitorr thermocouple gauge for each pumping station. The location of the vacuum pump manifold, where the 1-800 torr and 1-50 torr gauges are mounted with the pump valves that regulate the pump-down speeds, is shown in Figure 1-1 and Figure 1-4. Figure 1-4 shows that this pump manifold is forward of SI Safety Barrier, so can be accessed while the telescope is operating. The power switches for the pumps are located at the PI Console next to the Telescope Operator's Console (See Figure 1-1).

1.5.6 - Mission Audio Distribution System

The SOFIA intercom system provides TBD stations for communication between investigators, the mission director, and all support systems operations. Each station has a volume control, and a call-button to signal the mission director.

The IFD can place any combination of stations on one or the other of two channels (TBC). To facilitate this option, all passengers are encouraged to be aware of their station numbers. In addition, the IFD has additional channels available for separate communications with the flight crew or ground contact via the aircraft radios.

Figure 1-18. MADA Intercom Station Control Panel)

1.5.7 - Video Distribution System

Additional situational awareness and support for mission video archival is provided by the Video Distribution System (VDS). The VDS routes signals from a number of source, display and recording devices. Sources include the WFI, FFI and FPI imagers, cameras mounted in the TA cavity and crew compartments, workstation console displays, video tape players and connections available at the SI patch panel. Users may choose to route the video information from multiple sources, and to multiple destinations, simultaneously. Video may be displayed at any of the consoles, recorded to tape, or recorded via user-hardware connected at the SI patch panel.

1.6 - SSMOC Ground Facilities for SI Teams

The N-211 Hanger, which houses the SOFIA Science and Mission Operations Center, as well as the Airborne Observatory, includes a number of laboratory and office space for use by PI and General investigators.

1.6.1 - Visiting SI Team Labs and Offices

The NASA Ames aircraft hangar (Bldg. N211) has been refurbished to serve as the SOFIA ground facility, housing the SOFIA aircraft, and support facilities and staff. The building is approximately 300 feet by 300 feet, and four stories high. Three of the walls contain offices, meeting rooms, labs, and other work areas on three floors. The east wall consists almost entirely of motorized hangar doors that open to allow moving the SOFIA aircraft into and out of the hangar.

Facilities for SI support before and after flight are on the ground floor. These include two SI labs, and the Pre-Flight Integration Facility (PIF). Other areas offering support for SI teams include Science Support staff, computer and data archiving facilities, and the Mission Operations and Support (MOS) staff. The Science Support staff is led by the Project Scientist, the MOS staff by the MOS Associate Director, and both are directly under the Observatory Director.

1.6.1.1 - Facility Access

Due to the nature of the facilities, equipment and operations conducted within the SSMOC, access to the building interior and certain other areas within N211 is controlled at all times. All SOFIA employees and visitors receive appropriate training related to their work assignment or access needs and the SOFIA badge issued to them identifies their level of training and access clearance. Personnel without proper clearance or training may have access to all or most facility areas or the Observatory if accompanied by an escort in at all times. NASA Ames photo identification badges by themselves are not sufficient permit the wearer to gain access to the SSMOC without first obtaining a SOFIA badge in the lobby.

Access into the SSMOC through all exterior doors of N211 will be controlled through the use of locked or monitored doors. Access to the ramp area and SSMOC hangar floor will not be permitted to unauthorized personnel.

Examples of controlled areas within the SSMOC, which will require special access clearance, are aircraft parts/equipment storage rooms, UAL tool rooms, possible PI/GI labs and SIL.

SOFIA flight operations at NASA Ames will not be conducted on Saturday and Sunday. However, some limited SSMOC facility support will be available on weekends as needed, including access to SI labs, electrical power, network connectivity, and access into the aircraft if necessary.

Also, flight operations will not be conducted on 10 Federal holidays:

- New Year's Day (January 1)
- Martin Luther King Day (January 20)
- President's Day (third Monday in February)
- Memorial Day (last Monday in May)
- Independence Day (July 4)
- Labor Day (first Monday in September)
- Columbus Day (October 12)
- Veteran's Day (November 11)
- Thanksgiving (last Thursday in November)
- Christmas (December 25)

Note: Aircraft access may be precluded at any time by some maintenance tasks or other aircraft-related pre-flight activities.

1.6.1.2 - SSMOC SI Support Physical Facilities

The SSMOC floor plan is illustrated in Figure 1-19. Locations that SI teams and General Investigators are likely to be using or should be aware of include those listed in Table 1-8. The SI labs on the ground floor are intended for preparation of SIs for flight, and any post-flight work, such as calibration, diagnosis, or preparation for storage or shipping. Preparation for flight in the SI lab may include unpacking, electronics testing, assembly, inspections, vacuum pumping and initial cryogen transfers. This is also the location where electronics chassis can be installed into the SI rack(s) and the Counterweight Rack (CWR).

Table 1-8. SMMOC Locations

Name or Description	Rm.	~ Size	Location
SI Lab (and enclosed office)	129	29' x 19'	SW corner
SI Lab (and enclosed office)	130	29' x 19'	SW corner
Facility SI Lab	135	37' x 19'	Adjacent to west door
Pre-Flight Integration Facility	121	50' x 25'	South edge hangar floor
Elevator (4' wide door)		9' x6'	SW corner

Table 1-8. SMMOC Locations

Name or Description	Rm.	~ Size	Location
Guest Investigator office spaces	224-6	17’ x 10’	2nd floor, South side
Science Support staff offices	245-251	-	2nd floor, West side
SI, GI Workstations (terminals)	229	25’ x 15’	2nd floor, South side
DCS, MCCS support	218-221	-	2nd floor, South side

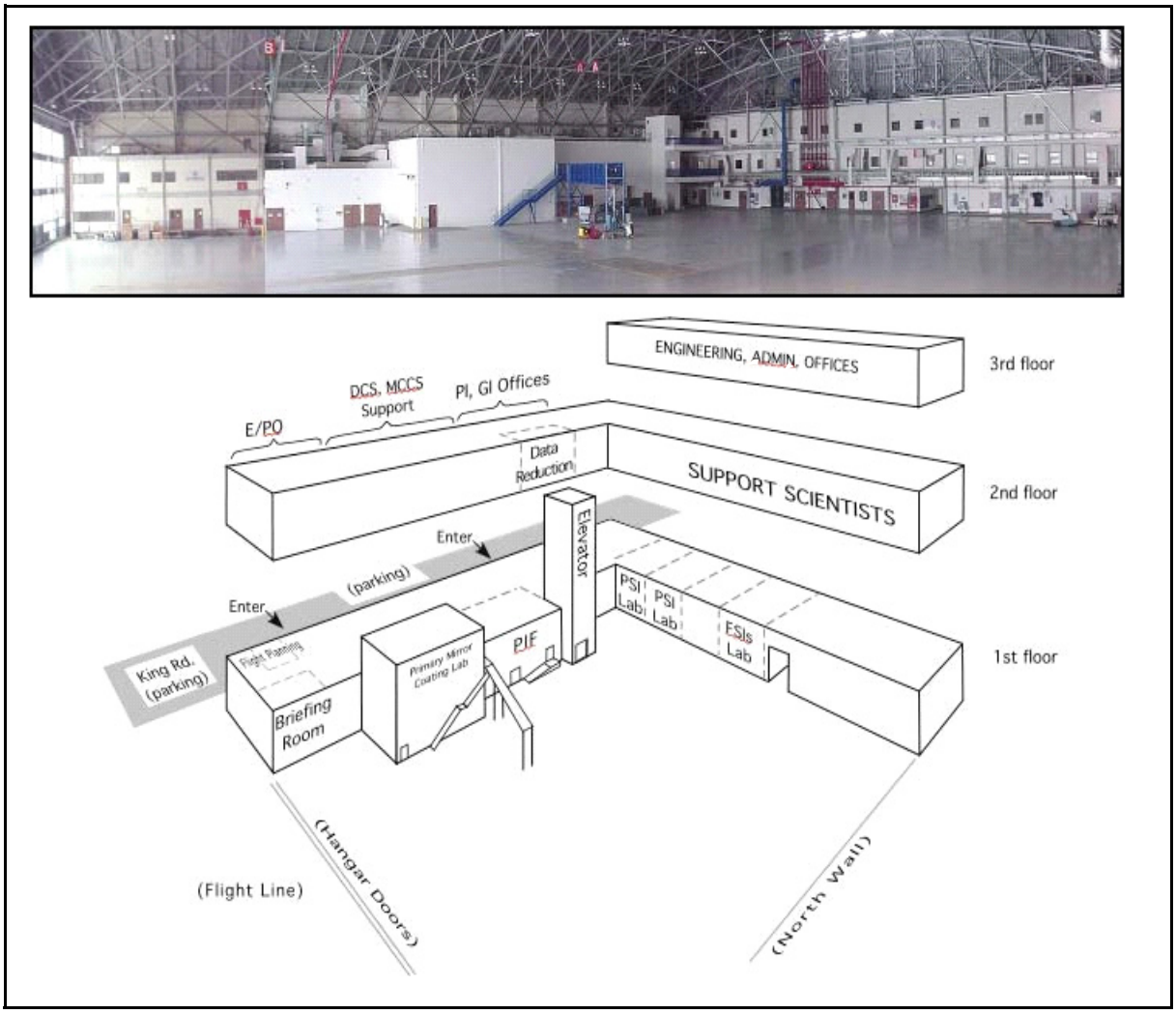

Figure 1-19. MOCC Floor Plan

Panorama of South and West Walls of the SMOCC (Bldg. N211), and schematic floor plan

Furnishings and utilities in the SI labs include several workbenches, 110V AC, Ethernet and telephone, a sink with potable water, and compressed air lines. Facility lab equipment and supplies available to use in the SI labs include:

- Portable roughing pump
- Portable turbo pump
- Helium leak detector
- 220V/60 Hz transformers (2 kVA each)
- Hydraulic lifting device
- Helium gas cylinder
- Nitrogen gas cylinder
- Liquid Nitrogen supply dewar
- Liquid Helium supply dewar
- Heat Gun
- Hand dewars
- Oscilloscope
- Digital Multimeters
- Bench power supplies
- Current/voltage source
- UPS
- Soldering station
- Fiber optics termination kit
- Spectrum Analyzer
- Logic Analyzer
- Signal Generator
- Lock-in Amplifier
- Electronic Filter
- Microscope
- Fiber optics inspection lamps

1.6.2 - Pre-Flight Integration Facility (PIF)

The TAAS is located in the Pre-Flight Integration Facility (PIF), at the south edge of the hangar floor. Acceptable installation of a Science Instrument onto the SOFIA telescope requires an air-worthy mechanical connection, and a fully adjusted and checked optical alignment. To evaluate and refine associated procedures, equipment handling and configurations involved, a high-fidelity replica of the Instrument Nasmyth Flange (INF) was used as the basis for the TAAS. A duplicate of the INF was provided by the TA contractor at the time of construction, and the dimensions are within ± TBD of the actual INF on the telescope. A schematic drawing of the TAAS appears in Figure 1-20.

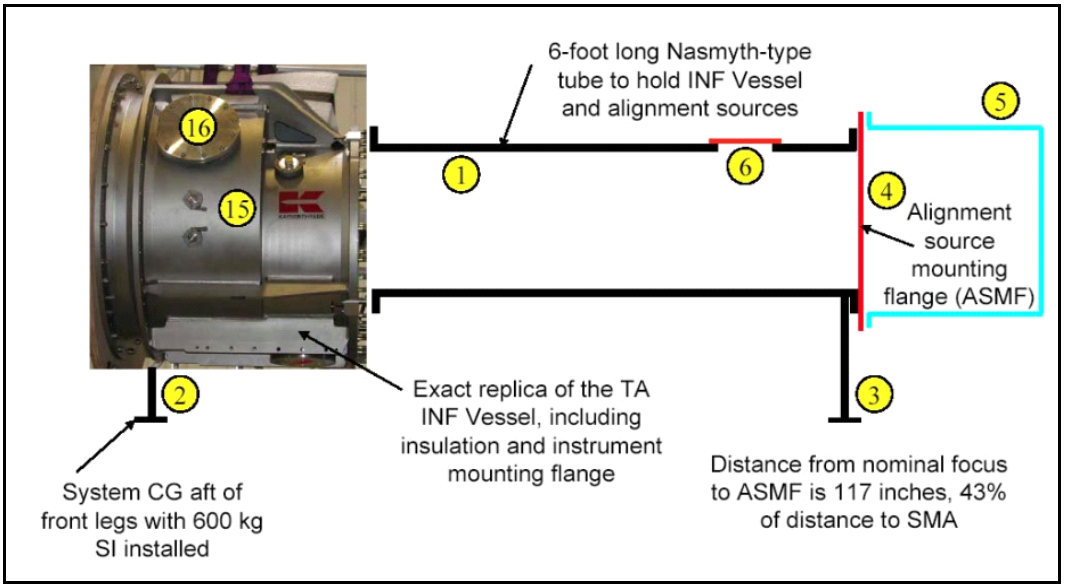
6-foot long Nasmyth-type tube to hold INF Vessel and alignment sources
16
15
1
6
5
4
Alignment source mounting flange (ASMF)
2
3
Exact replica of the TA INF Vessel, including insulation and instrument mounting flange
System CG aft of front legs with 600 kg SI installed
Distance from nominal focus to ASMF is 117 inches, 43% of distance to SMA

Figure 1-20. TAAS Schematic

A photo of the replica of the INF is shown in Figure 1-20. A 2-meter long tube connects this to a mounting area for alignment sources. Both the INF replica and the attached tube are elevated on supports, at a height similar to the nominal height of the actual telescope INF above the aircraft cabin floor.

Three alignment measuring devices are available with the TAAS. These include a modified Portable Chopped Light Source (PCLS), adapted from the KAO unit, a diffuse-emitting chopped hot plate, and an optical boresight camera.

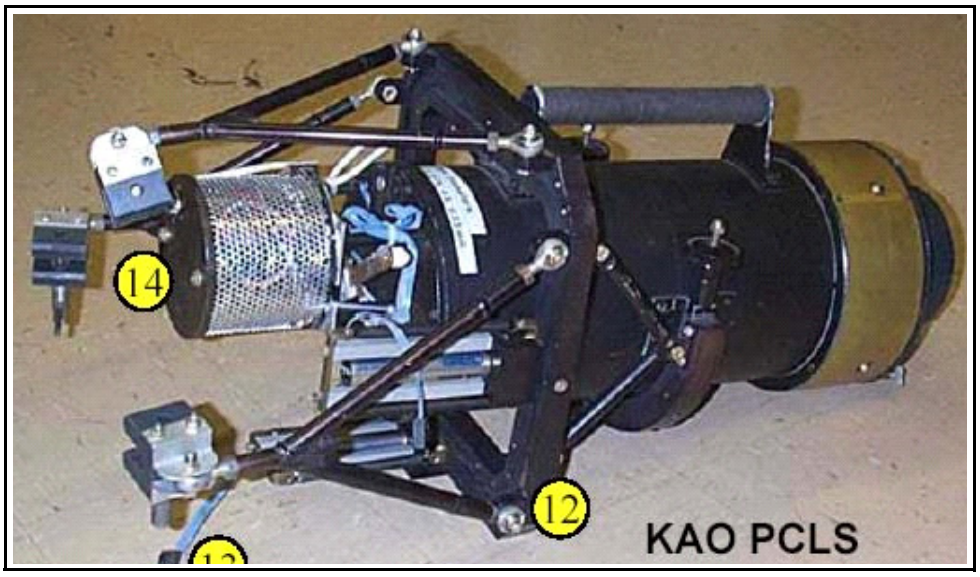

Figure 1-21. Portable Chopped Light Source

The PCLS provides a focused beam of IR and visible light, with f-ratio ~18. The actual distance to the focused image can be adjusted by moving the secondary mirror of the PCLS. The PCLS optics are mounted in a motorized gimbal, so that the location of the image produced by the PCLS can be translated in the SI focal plane. When the chopped PCLS image has been positioned and focused for maximum IR signal from the SI (perhaps from a selected pixel of an array), then a diverter mirror can be inserted in front of the SI, and the location and back-focus of the visible component of the PCLS image can be observed and measured using the TAAS boresight camera. The PCLS can use an external TTL synch signal from the SI, via a BNC connector on the PCLS control chassis.

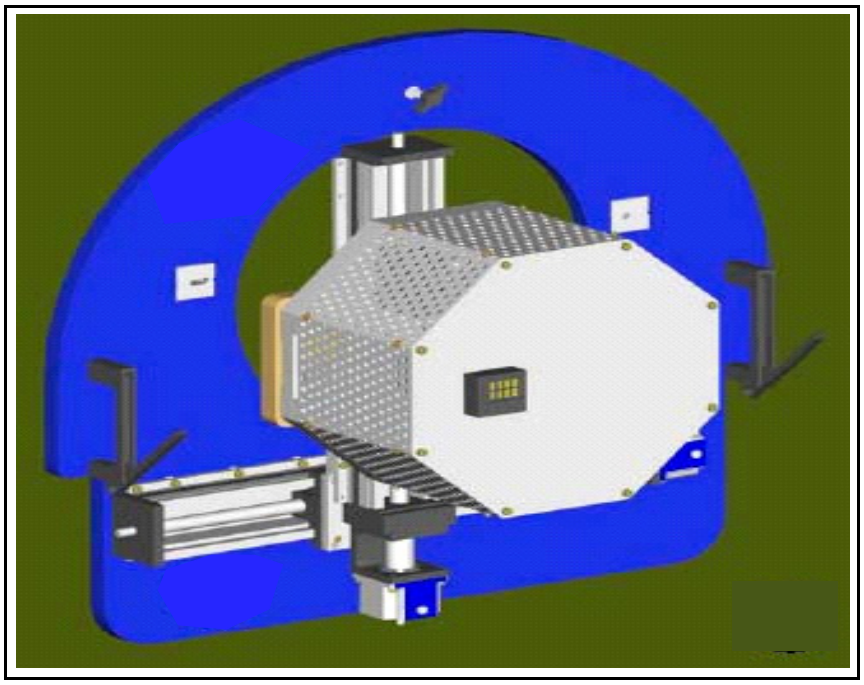

Figure 1-22. View of Chopped Hot Plate Mounted at End of TAAS

The chopped hot plate mounts in the same location at the far end of the TAAS. It provides a chopped IR-bright disk, which can be used to verify that an SI pupil is aligned, or that an SI spatial response pattern (a.k.a. antenna pattern or central response lobe) is centered on the direction to the center of the telescope secondary mirror. The chopped hot plate is mounted on an x-y stage, so it can also be used to map an SI spatial response pattern. This device also accepts an external TTL synch signal from the SI. The IR emitting area is 15 cm diameter (TBD) , and is located 3 meters (TBD) from the equivalent of nominal focus location, 30 cm outside the INF SI mounting surface.

After either one of these sources are mounted on the TAAS, an airtight enclosure may be installed, and the light path to the SI may be purged with dry nitrogen gas if desired.

Note: Nitrogen purging should be coordinated in advance with the Mission Operations and Support (MOS) manager on duty.

The TAAS is located in the center of the PIF, and sufficient floor space is available for one or more SI racks and any other equipment needed.

1.6.3 - Computational Facilities

Other computational support facilities in the N-211 hangar include additional workstations and terminals linked by an Ethernet network, which in turn is linked to the Internet. While the SOFIA 747SP is parked in or near the hangar, the aircraft network may be connected to the hangar net-

work (and so to the Internet) by a 200-foot co-axial cable. The Internet address for the system administrator of the Bldg. N-211 network is:

sysadmin@sofia.arc.nasa.gov

1.7 - Software and Data Management

1.7.1 - Observatory Software Simulator

The basic architecture of the computer network and software on the aircraft has been reproduced in a self-contained "SOFIA Simulator", located on the second floor of building N-211. The Simulator contains a Sun Sparc workstation and other devices necessary to represent an experimenter's workstation, the PI patch panel, the SCL, the two Ethernet networks and associated I/O devices. The instrument teams may bring their own rack of equipment alongside, make connections to the Simulator analogous to those to be used on board, and perform dry-runs of data taking through an authentic interface environment. This may be useful before an experiment is installed into the aircraft, or on weekends and/or deployments where power or access to the aircraft may not be available. Shortly after the SOFIA Operational Readiness Review in 2005, the capabilities of the SOFIA simulator hardware will be limited. Over time, however, USRA will fund the development of the simulator to off-load the task of system integration and maintenance to the N-211 facility.

1.7.2 - Flight Management (FM) Software

FM is responsible for developing, executing and re-planning SOFIA flights based on observing plans developed by users of the Observatory. Most FM functions are carried-out pre-flight, in the SSMOC, to optimize the route and altitude profile required for observations. Portions of FM are also active on-board, providing flight monitoring to the IFD and rudimentary input to the aircraft's autopilot for maintenance of desired headings.

FM produces two forms of the flight plane, one to be filed with the FAA for subsequent use by air-traffic control, and one to be used by the IFD in monitoring and controlling adherence with the flight plan. The IFD uses FM's "Flight Executor" sub-function to monitor performance against planned ground track in the presence of disturbances (due primarily to unplanned wind velocity/direction or revisions to planned observations). If deviations exceed expected ATC tolerances, the IFD uses FM to re-plan remaining flight legs for subsequent re-filing with the FAA.

1.7.3 - Observatory Data Archive

The SSMOC has a Data Cycle System (DCS) which is an integrated environment with computational modules, planning tool and databases. Some of the modules are commercial-off-the-shelf

(COTS) software. Others are custom programs written by specialists. The system design is modular and has an architecture that can accommodate interfaces with many external components and has the flexibility to change over the lifetime of the SOFIA mission,

The DCS architecture is designed as a distributed system with user access via the Web. The user interface is personalized by the application of XML and XSL/DSSSL, yielding web pages (HTML) unique for each user's need. The archive software system employs a Java front-end connected to an Informix RDBMS backend.

1.7.3.1 - Archive Access

Access to the SOFIA archive is through the web. GIs and PIs can obtain their data from the archive during the proprietary time period using their assigned DCS login and password. Other archive users can register with the archive and obtain a valid user name and password for access if they want to retrieve public data from the archive. Any user can browse the archive without being a registered user.

Search and retrieval of science data will be similar to most astronomical data archives. Data can be searched based on:

- Project ID, observer names
- Source name (name resolver - SIMBAD or NED), source type
- Coordinates or coordinate range
- Instrument, filter, frequency or wavelength, observing mode
- Date or time range

A query may also be a combination of several search parameters. Additionally, special queries of any keyword or range of values in a keyword stored in an instrument (FITS) data header may be executed by SSMOC archive analyst using SQL. The archive user interface is still being designed and the details of the browser are therefore TBD.

1.7.3.2 - Summary Archive

The SOFIA archive does not contain a special summary archive. Summary information is retrieved from stored metadata information and is available to the astronomy community through the archive browser. How the browser will format this information to a user is still TBD, but any summary listing will contain at least the following information: Project id, name of observer (PI), Instrument, filter, observing mode, integration time, water vapor overburden, date, flight and flight leg, source name, coordinates (in J2000). The amount of the summary information will be configurable by archive users.

1.7.4 - Pipeline Products

Pipeline reduced data are available only to accredited users during the proprietary period, and to the whole user community after the end of the proprietary period.

1.7.5 - Housekeeping (HK) Data

Access to HK data will be through a special engineering interface hosted by the DCS. This query interface will enable SSMOC staff and DCS accounts to access any data based on keyword, keyword value, time (date or time interval) or any combination of these. MCCS is providing on-line tools for monitoring, displaying and analyzing HK data. The same tools will be available as stand alone versions for analysis of HK archive data.

1.7.6 - Retrieval of Data

All data retrieval from the SOFIA archive will be through an ftp server. GIs retrieving their own data will have the highest priority if data retrieval needs to be staged; SSMOC staff will be next in priority and registered data miners will have the lowest priority. A single user can retrieve at most 10 GB of data at one time. Requests for abnormally large (i.e., > 10 GB) data sets will have to be sent to the SOFIA Observer Support and will be handled on a case by case basis

1.7.7 - User Volumes and Initial Hardware Requirements

Initially the number of SOFIA archive users is expected to be rather small. The user base will grow rapidly once science data become public and with accumulation of new data (and increased observing efficiency) for each observing cycle.

The archive is therefore designed to be expandable, both in terms of storage capacity and server capacity (i.e., how many simultaneous users the archive can support). Since storage media, servers and data links become cheaper every year, there is no reason to over-design the archive. During the first year of operations we expect to have at most 10 simultaneous archive users, which can be handled by three high performance workstations running the archive software (including the Informix server), one web server and one FTP server. The media for data storage will initially be hard disks, with backup on two additional sets of hard disks.

CHAPTER 2

SOFIA Science Instrument ICDs

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2.1 - Introduction

This section of the SOFIA Handbook concerns the selection, design, fabrication or modification of experiment apparatus used on board the SOFIA 747SP on the ground or in flight. The information in this section addresses the following general categories:

- Size and weight specifications for equipment mounted on the telescope, and for apparatus mounted in instrument racks.
- Equipment and facilities either required for use, or that are available for use as part of the experiment installation or operation. These equipment and facilities include the standard instrument rack, electrical power sources, and equipment available before, during, and after each flight.
- Aspects of the aircraft cabin environment that may be relevant to the experiment design or performance (e.g., temperature, vibration and radio frequency interference).
- The inspection and approval process for installation of an experiment into the aircraft; including areas of concern and required documentation.
- Suggested techniques for fabrication and assembly that can contribute to improving the performance and reliability of the experiment throughout a mission (series of flights).

An outline of the SOFIA safety and airworthiness guidelines are presented in Chapter 3, “Airworthiness” on page 3-1. The detailed science instrument airworthiness manual is contained as Volume III of this series.

Installation of research equipment can be very demanding and time consuming if adequate precautions are not observed. To prevent a disappointing last-minute delay or cancellation of a flight or mission because of incompatibilities, instrument designers should follow the guidelines in this chapter relating to environmental factors, physical constraints and airworthiness considerations.

2.2 - SOFIA Aircraft and Telescope Coordinate Systems

With the selection of the USRA proposal, NASA purchased the “Clipper Lindbergh” 747-SP aircraft (Boeing production number 21441) from United Airlines in January 1997. The aircraft was later flown to the L-3 facility in Waco, Texas for modifications required SOFIA development program. Overall aircraft modifications included major revisions to the aricraft’s aft structure, modifications of the aircraft interior for scientists and educators, creating a cavity in the aircraft fuselage to house the German telescope, and installing all the required observatory support systems. As indicated previously, the final layout of personnel accommodations includes workstations for a mission director, telescope operator, and computer specialist, as well as work areas designated for scientists and educators. The 747-SP aircraft structure provides the initial fundamental coordinate system for SOFIA development program.

2.2.1 - Aircraft Coordinate System

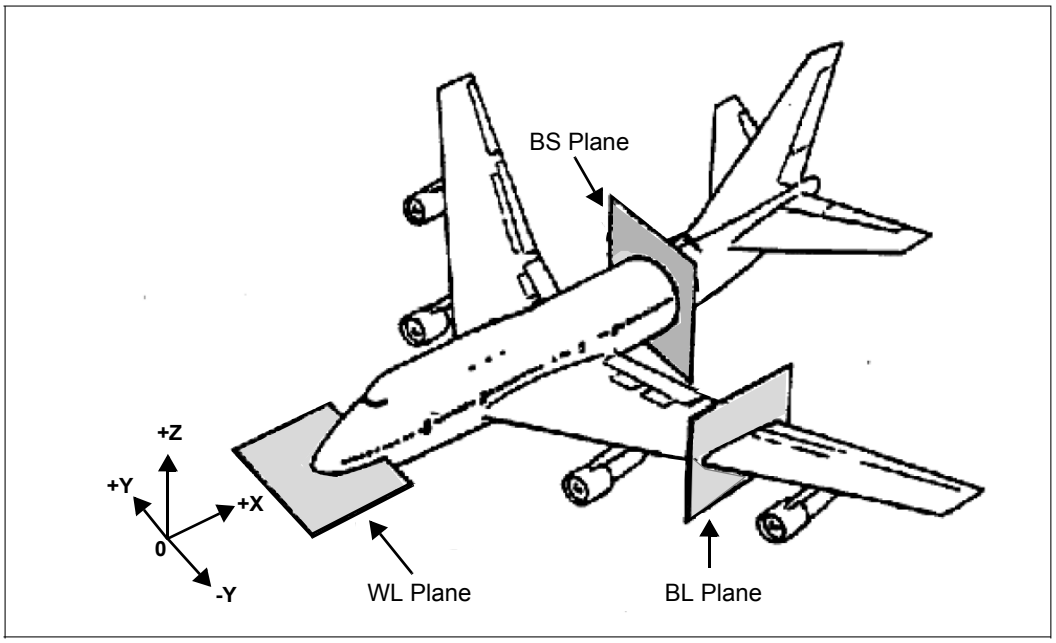


Figure 2-1. SOFIA Aircraft Coordinate System

The aircraft coordinate system follows the Boeing convention with positive X pointing towards the rear of the aircraft, positive Y pointing out the right-hand side (waterline plane), and positive Z pointing up (buttline plane) as defined by the 'right hand rule, or X cross Y equals Z'. The yaw, pitch, and roll angles correspond to rotations about the X, Y, and Z axes, respectively. The water-line (WL) and buttline planes (BS) are illustrated in the figure above.

The origin of the coordinate system is located 7366 mm (290 inches) forward of the aircraft nose, at the intersection of waterline 0 and buttline. The waterline plane (WL in Figure 2-1) is defined as positive bottom to top, and the buttline plane (BL) is defined as positive pointing to port. In this coordinate system, the center of the telescope's spherical bearing is located at X = 43,942 mm (1730 inches), Y = 0 mm, and Z = 5,867.4 mm (231 inches).

2.2.2 - Telescope Coordinate System

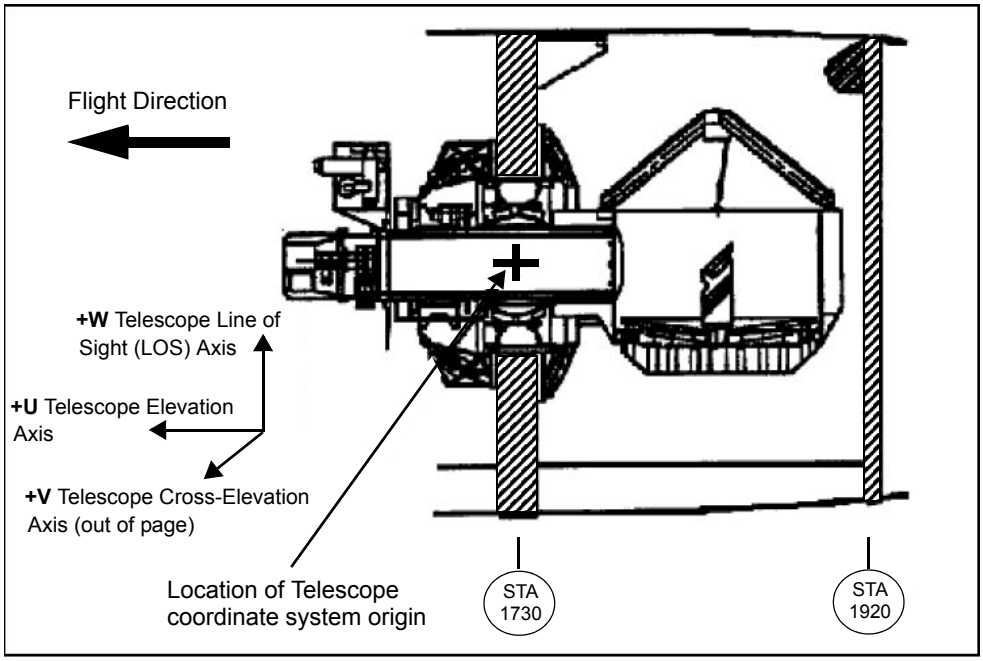

Flight Direction
+W Telescope Line of Sight (LOS) Axis
+U Telescope Elevation Axis
+V Telescope Cross-Elevation Axis (out of page)
Location of Telescope coordinate system origin
STA 1730
STA 1920

Figure 2-2. The SOFIA Telescope Coordinate System

U, V, W coordinate system moves relative to the aircraft with the origin at the center of the spherical bearing.

A second coordinate system – the U, V, W coordinate system – is defined for the telescope, which moves relative to the aircraft. The origin of this telescope coordinate system is at the center of the spherical bearing. As shown in Figure 2-2, the U-axis points along the Nasmyth tube into the cabin, the W-axis is normal to the Nasmyth tube and parallel to the primary-mirror optical axis, and the V-axis follows the right-hand rule, or 'U cross V equals W'. Hence, when the telescope is pointed straight up (i.e., elevation angle = 90°), the U and W axes lie in the plane of the page and the V axis is normal to the page. With the telescope in this orientation, U points in the negative X-direction, V points in the negative Y-direction, and W points in the positive Z-direction. The elevation (EL), cross-elevation (XEL), and line-of-sight (LOS) angles correspond to rotations about the U, V, and W axes, respectively.

2.3 - SOFIA Telescope Optical Prescription

The architectural design of the SOFIA telescope assembly (TA) is shown in Figure 2-3. The optical design of the TA is a classical Cassegrain with a Nasmyth focus. A classical Cassegrain system consists of two imaging optical elements: a concave, parabolic, primary mirror and a convex, hyperbolic secondary mirror. The primary forms a perfect (i.e., totally free of geometric aberra-

tions) on-axis image of an infinite point object. This image is placed at the virtual image of the secondary-mirror. The latter then forms an on-axis perfect image of the primary-mirror image in the TA focal plane. The Nasmyth focus is achieved by folding the optical beam via a flat tertiary mirror onto an actuation axis of the TA for more convenient access to the focal plane image.

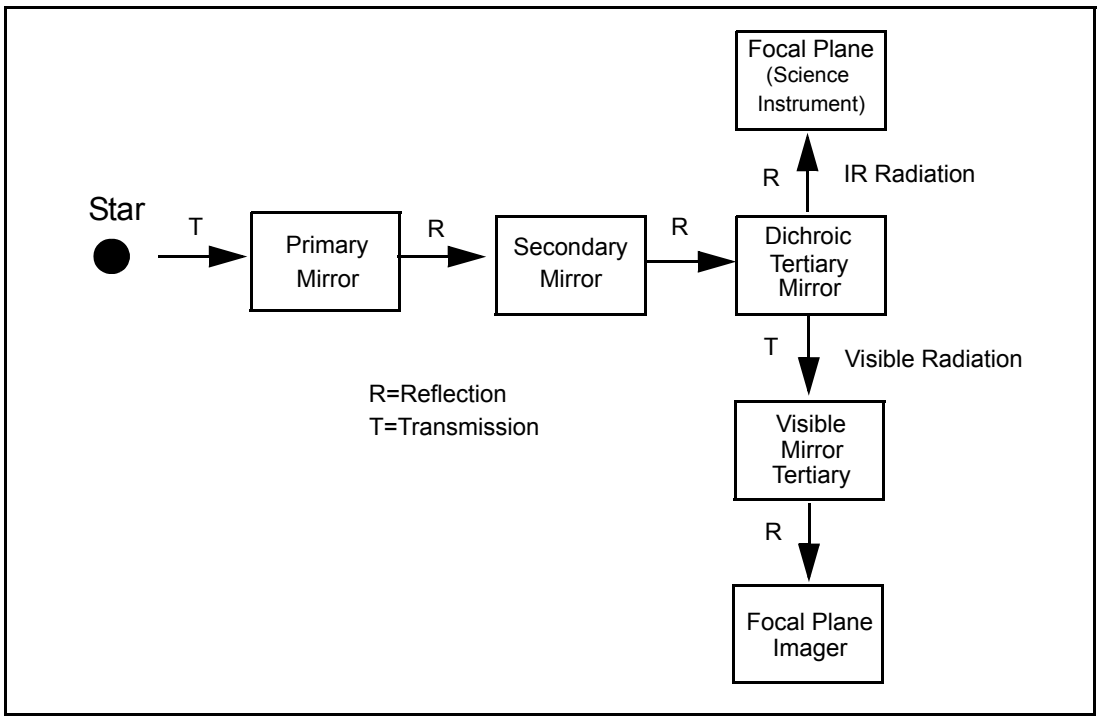


Figure 2-3. Architectural Design Description Of The SOFIA Telescope

Classical Cassegrain optical design with a Nasmyth focus, featuring a concave primary mirror and a convex secondary mirror. The Nasmyth focus results from folding the optical beam via a flat tertiary mirror onto an actuation axis of the TA.

The optical design of the SOFIA telescope is described in SOF-SPE-KT-1000.0.03. The main mechanical distances are shown in Figure 2-4.

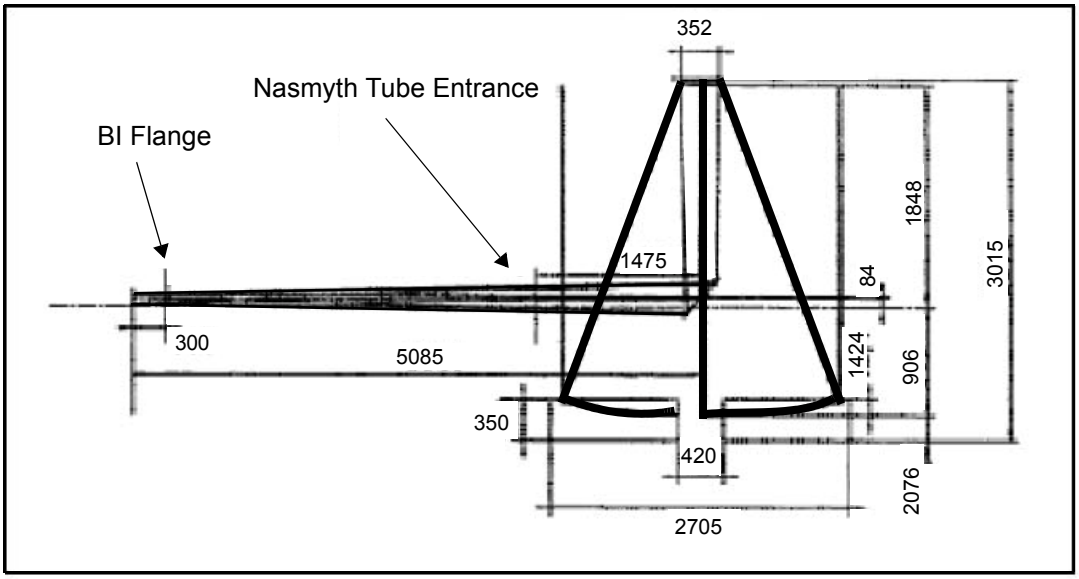


Figure 2-4. Optical System Configuration of the SOFIA Telescope Assembly

Nominal mechanical distances in millimeters between optical components of the SOFIA telescope assembly.

The first order optical data for the TA is given in Table 2-1. Since the telescope is refocused with its axial actuated secondary mirror, all first-order data like the effective telescope focal length and the entrance pupil size are functions of the back focal distance, which depends on the science instrument design. Axial movement of the secondary mirror for refocusing introduces optical aberrations. Only at nominal focus does the telescope provide a perfect Cassegrain image free of axial geometric aberrations. As the telescope is refocused at different back focal distances, spherical aberration is introduced. Details on the changes in image quality with telescope focus are provided in the SOFIA technical document SOF-SPE-KT-1000.0.03.

Table 2-1. Telescope Assembly Optical First Order

First Order Parameter	Value
Entrance pupil diameter	<= 2500 mm (8.2 feet)
Nominal focal length	49141 mm (161.2 feet)
Unvignetted field of view	±4 arcminutes for chop amplitudes up to ±5 arcminutes off-axis
Aperture stop location	Secondary mirror
Aperture stop diameter	352 mm (13.9 inches)
FPI eyepiece focal length	785 mm (30.9 inches)
Nominal FPI exit pupil diameter	40 mm (1.6 inches)

Table 2-1. Telescope Assembly Optical First Order

First Order Parameter	Value
FPI angular magnification	62.6
FoV at FPI exit pupil	±4.2 arcmin

2.3.1 - Secondary-Mirror Buttons

The secondary-mirror button defines the central aperture stop for the telescope and prevents science instruments from imaging themselves. Specifically, the button ensures that the primary-mirror hole and the edges of the tertiary mirror are not visible in the science instrument focal plane. The details of the button design depend on wavelength and other science-instrument specific considerations. For example, some buttons are reflectors ("scatter-cones"), deflecting cold sky emission into the focal plane, while others are flat, high-emissivity (black) absorbers. In some cases, buttons may have optical surfaces that are asymmetrical with respect to the secondary-mirror axis, as the central obscuration of the telescope can be minimized if the buttons optical surface is decentered (see SOFIA Technical Note SER-ASD-023).

Science instrument teams can select a suitable secondary mirror button from several provided by USRA or they can design and build their own. The details of the secondary mirror design requirements are found in SOFIA Document TA_SSMO_09.

Two possible secondary-mirror button designs are illustrated in Figure 2-7. The dimensions given in these figures are only approximate. Final dimensions depend upon the material selected for the secondary-mirror and button. Both designs show exposed screw heads on the button surface facing the primary mirror; these represent x% of the button surface and, if painted black to suppress star-light, produce a negligible increase in telescope emissivity (< 0.1 %). "Clip-on" secondary-mirror buttons designs are also possible, provided they meet all in-flight loading specifications.

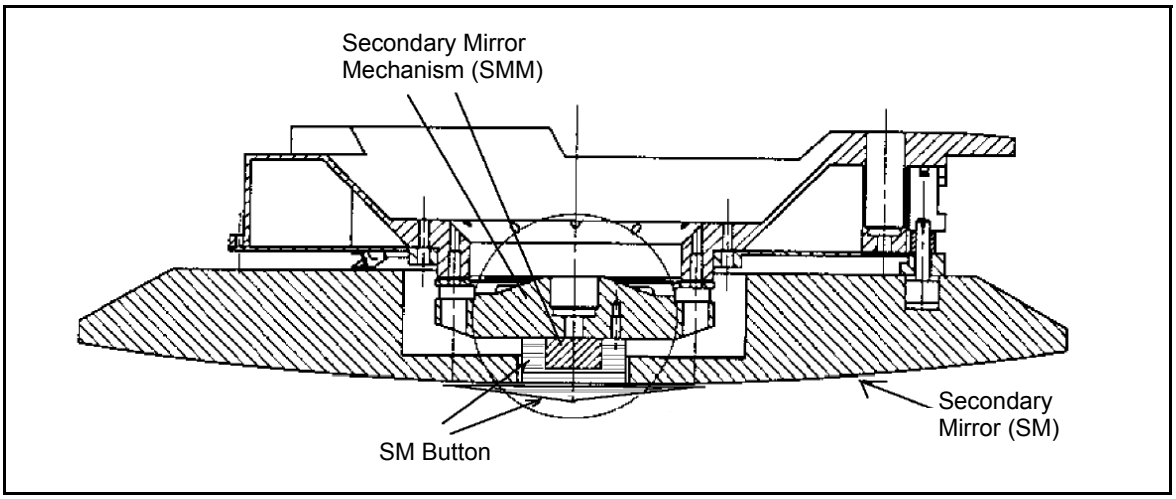
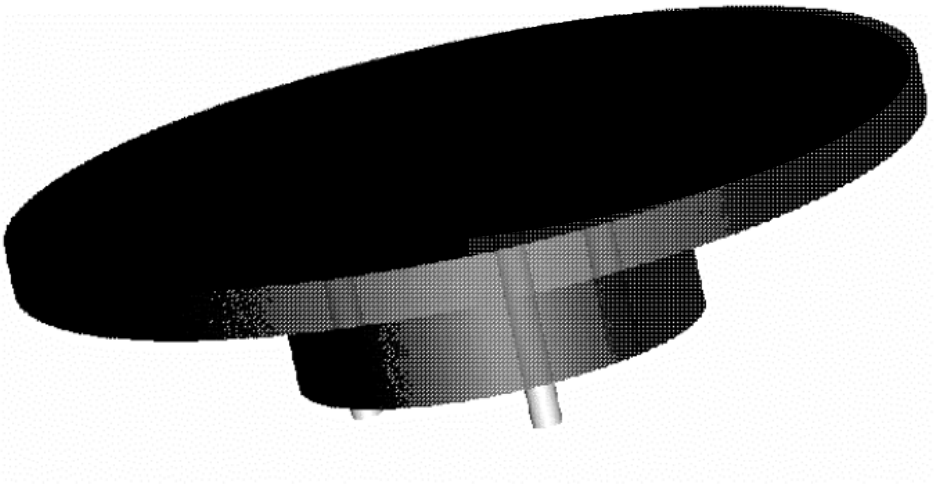
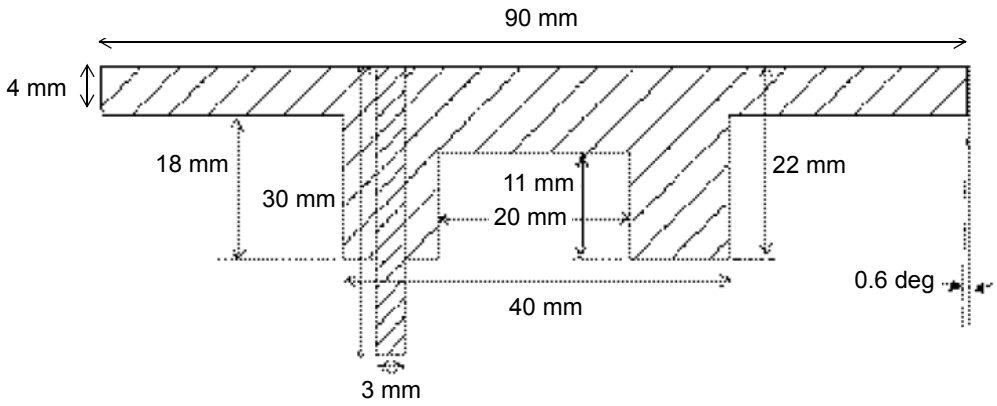


Figure 2-5. Secondary-mirror Assembly Cross-Section

Cross-section of the SOFIA secondary-mirror assembly with the baseline concept of the secondary-mirror button installed.

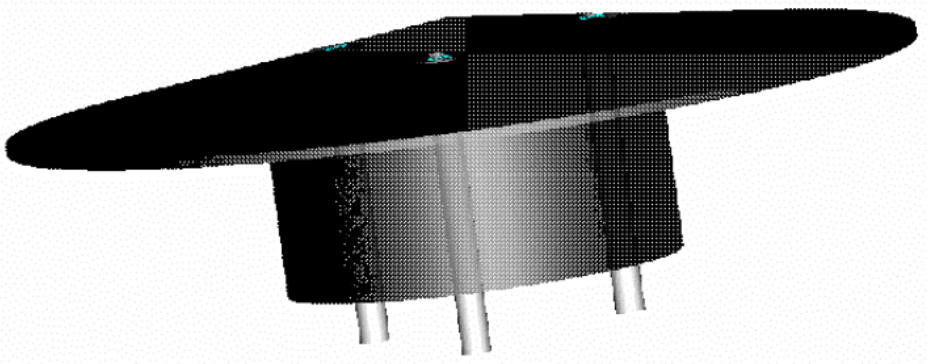


Concept of a Flat Black SM Button

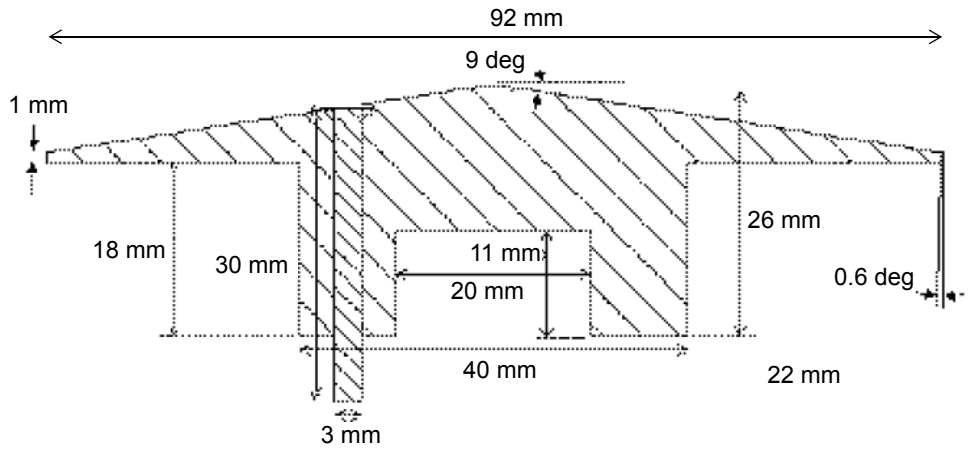


Cross-section of Flat Black SM Button

Figure 2-6. Secondary-mirror Button Design (Flat Black)



Concept of Conical Reflecting SM Button



Cross-section of Conical Reflecting SM Button

Figure 2-7. Secondary-mirror Button Design (Conical Reflecting)

The above two examples shown are a flat black unit and a conical reflecting surface design. Instrument teams may design their own with approval from USRA.

2.4 - Telescope Mounting-flange

Science instruments mount at the instrument-mounting flange (IMF). The IMF is part of the Nasymth tube and is located at the forward end of the telescope. The part of the science instru-

ment that mounts to the IMF is called the science instrument flange (SI flange). Figure 2-8 shows a detailed, three-dimensional representation of the forward end of the Nasymth tube, including the IMF. Figure 2-9 shows a cross-section of the TA structure and its surroundings.

The structural requirements for the IMF assume a single shear pin and 20 bolts with nuts support the science instrument. The bolts, located on a 41-inch bolt-circle centered on the infrared beam, are equally spaced in angle. The bolt-holes in both the IMF and SI flange must be through holes. The nuts are optionally secured with the appropriate nut-plates. There are two 20-bolt hole patterns offset from each other; one has nut plates while the other does not. USRA will provide and install all the bolts, nuts, and nut-plates required to mount science instruments to the IMF.

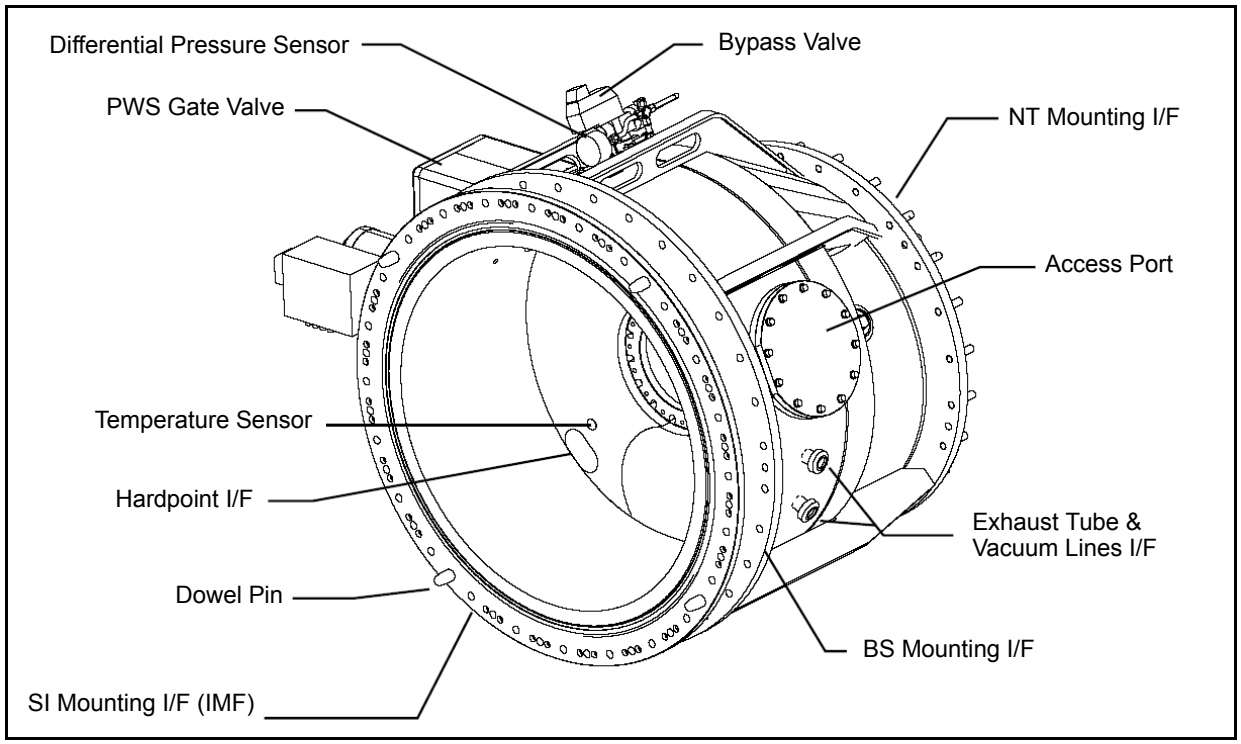


Figure 2-8. 3-D View of the Science Instrument Flange

A 3-D View of the instrument mounting flange with noted points of interest. Science instrument bolt directly on the flange using 20 USRA provided fasteners. Two dowel pins provide accurate and repeatable alignment of science instruments with respect to the optical axes of the SOFIA telescope.

The maximum allowable instrument weight is 600 kg (1320 lbs). The maximum allowable moment about the air bearing for an instrument is TBD ft-lb. Therefore, the center of gravity of a maximum weight package must be no more than TBD inches forward of the hydrostatic bearing, or TBD inches forward of the IMF mating surface. Longer moment arms are acceptable if the weight of the package is proportionately less. Instrument teams should note that a fence restricts access to science instruments during flight. Special permission is required from the in-flight

director to access the instrument within the designated perimeter while the TA is activated during normal flight operations.

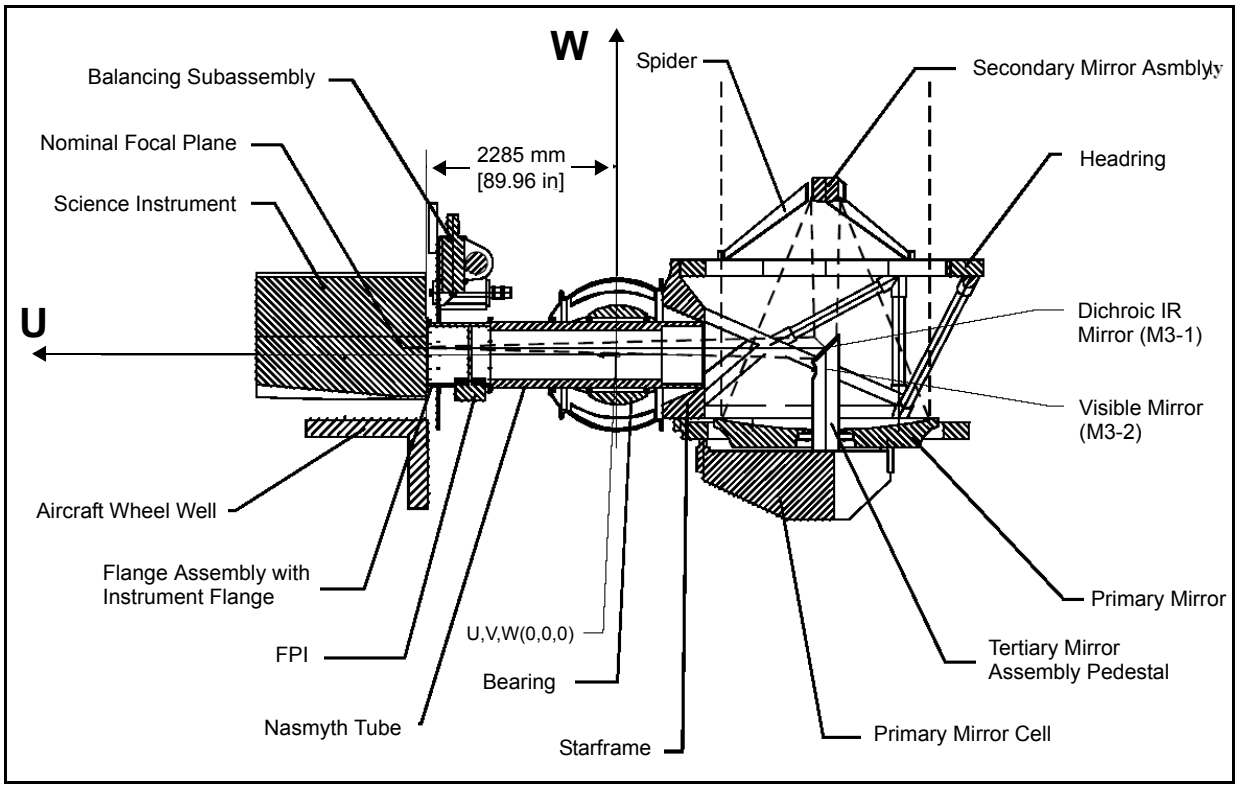


Figure 2-9. Mechanical Telescope Assembly System Configuration With A Mounted Science Instrument

The pressure-boundary for a science instrument can be made:

a. At the instrument mounting flange;

b. To the telescope gate valve;

c. With a separate window attached to the gate valve.

Some possible configurations are shown in Figure 2-16.

The IMF includes 4 precision-machined dowel pins, equally spaced on a TBD-inch bolt circle and separated by 90°. One of the dowel pins has to take the shear forces in the event of a crash landing and during extreme telescope maneuvers (i.e., slamming into telescope hard stops). Since the fasteners for the IMF use only through-holes, accurate positioning of a science instrument requires two of these pins: one for position and the other for angle. Four jackscrews are provided to assist in the removal of science instruments after a mission is completed. Four additional hard points inside the Nasymth tube tub are available for mounting other science instrument hardware.

The two dowel pins not in use by a particular science instrument can be removed temporarily if desired or required.

There is free volume inside the flange-assembly between the IMF and the gate-valve pressure window subassembly. This volume can be used for different purposes, including a bore-sight box, calibration source, or the mounting of small science instruments.

The complete engineering details for the IMF are contained within the interface control document TA_SI_02.

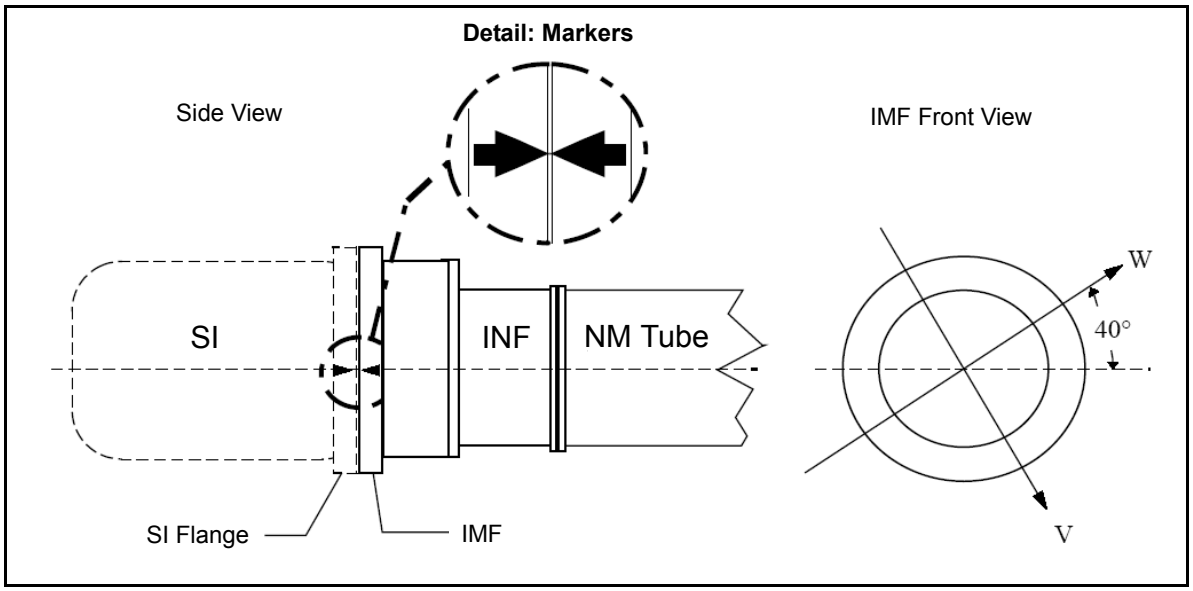


Figure 2-10. The Orientation Marker Inscribed On The Circumference Of Instrument Mounting Flange

An orientation marker is provided to register the instrument mounting flange and the science instrument flange. The schematic shows the orientation of this marker with the UVW coordinate system of the telescope.

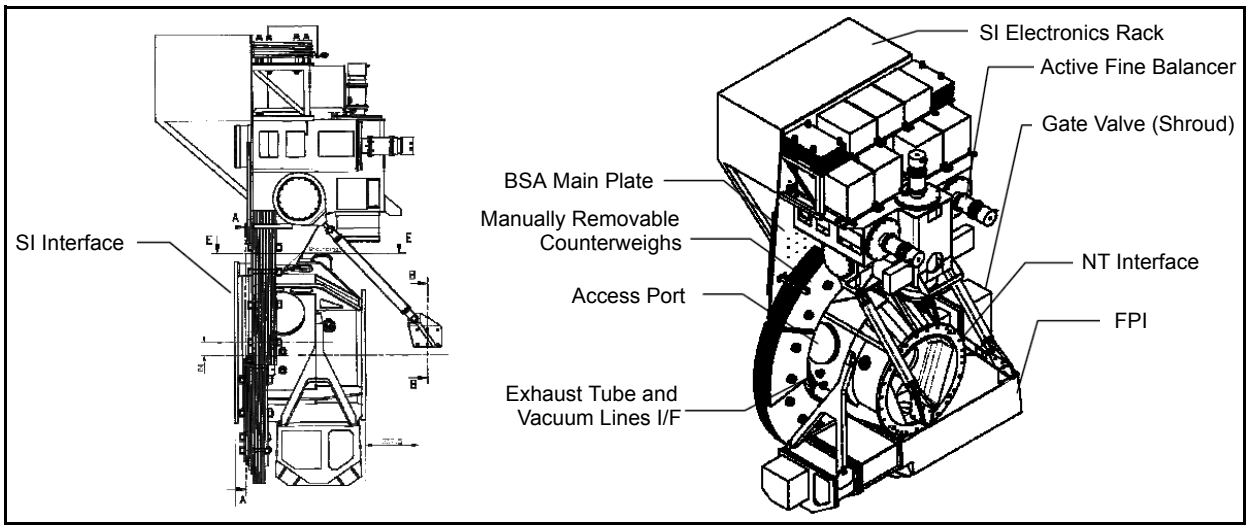


Figure 2-11. Schematic Sketch of the SOFIA Flange Assembly

Schematic shows flange-assembly without the cable load alleviator, illustrating volume between the IMF and gate-valve pressure window subassembly. Available space can be used for purposes including a bore-sight box, calibration source, or mounting of small science instruments.

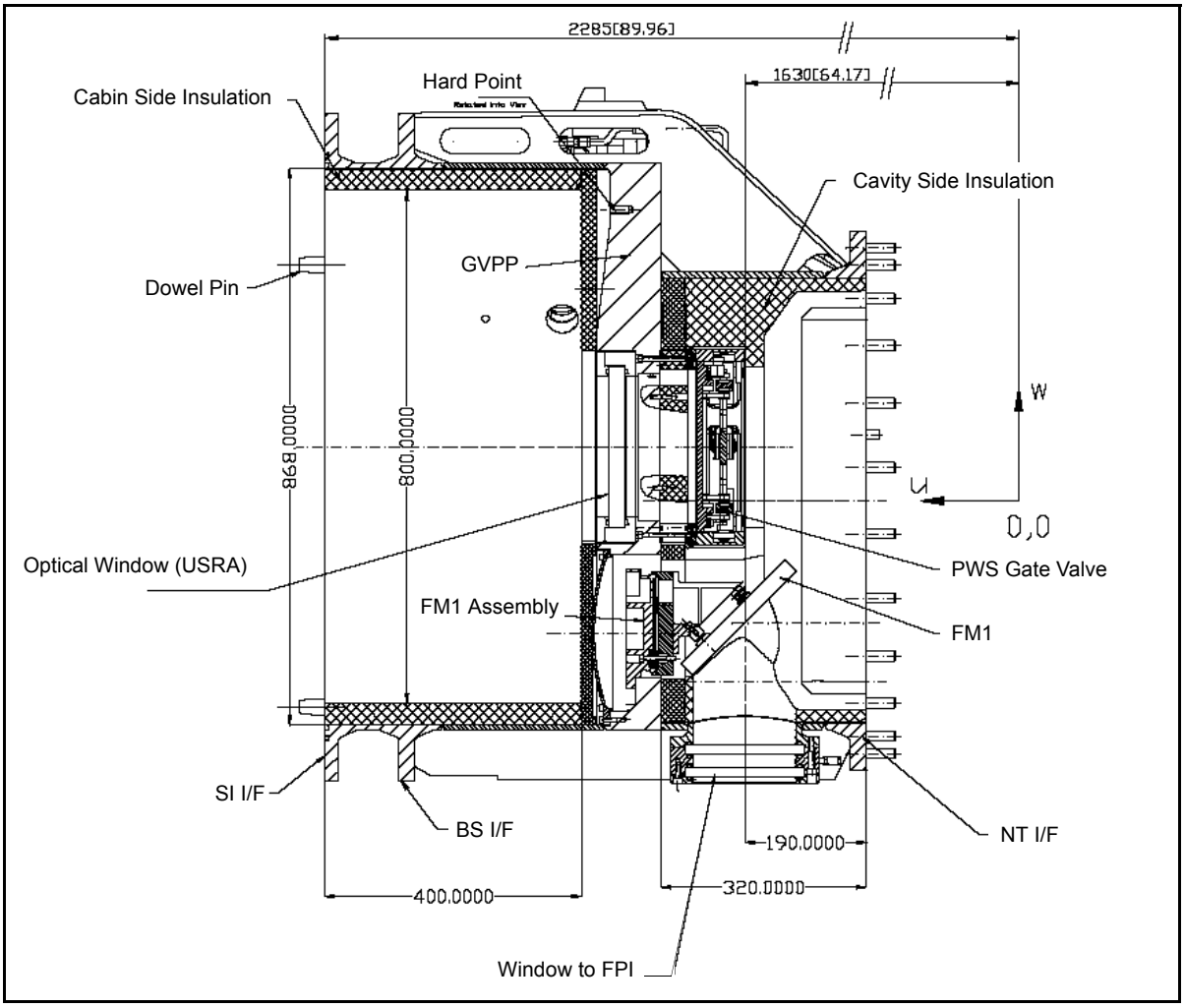


Figure 2-12. A Cross-Section Of The Instrument Flange And Pressure Window Assembly Without The Counterweight Subassembly

Details of the instrument flange for mounting SOFIA science instruments is shown with physical dimensions in millimeters. The details of this interface are contained with TA_SI_02.

2.4.1 - Science Instrument Flange Hard Points

In addition to the pressure couple/optical window assembly interface, there are four tub hard points on the gate valve pressure plate located on a diameter centered on the IR beam optical axis. It is expected that the hard points will be covered by pieces of thermal insulation during normal operations. The hard points provide locations for supporting instrumentation within the Nasymth tube and forward of the telescope gate value. This might include an extended pressure coupler or a partial science instrument flange.

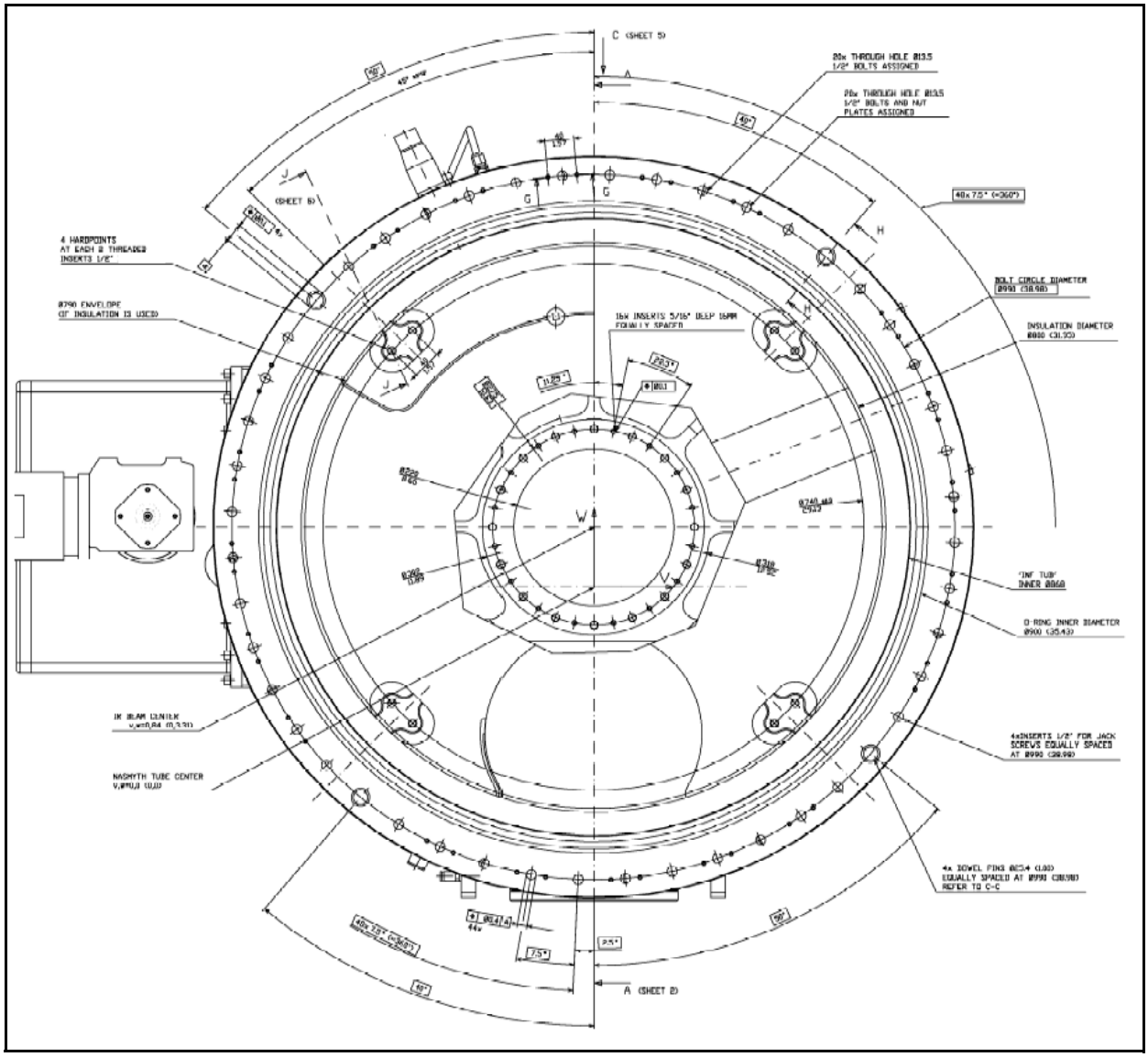


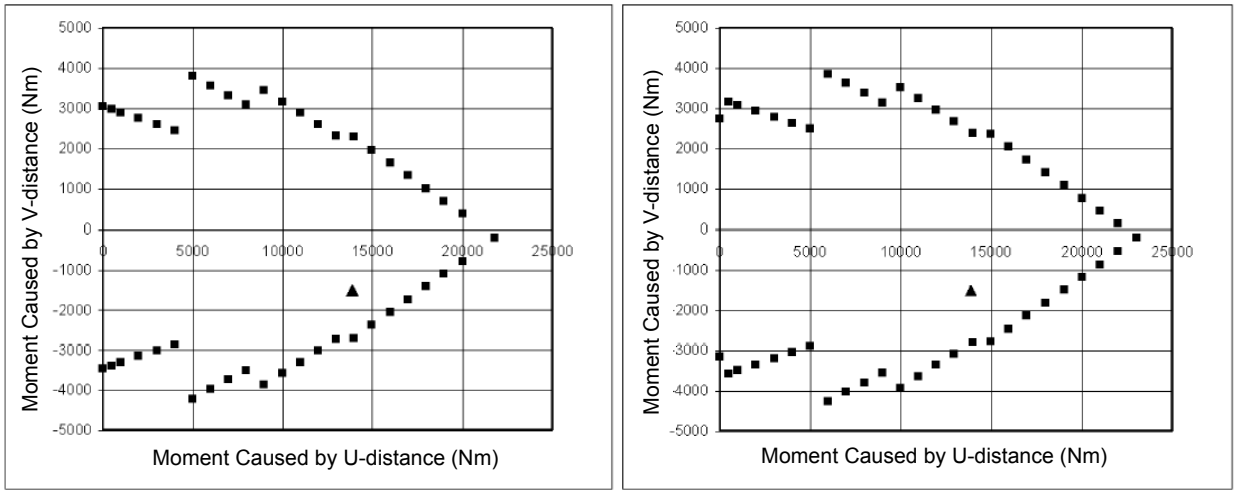
Figure 2-13. Front View of the Instrument-mounting Flange

A front view of the instrument-mounting flange showing the location of the dowel pins, the IMF bolt circle, the four tub hard points, and the pressure coupler/window bolt circle. This figure illustrates the telescope at an elevation of 90° where the nominal installation elevation is 40°.

2.4.2 - Mass and Center of Gravity of Science Instruments

Because of the numerous possible configurations of science instruments, the mass and center of gravity between instruments is expected to vary. The telescope requires that the instrument mass is less than 600 kg (1322.8 lbs) and that the center of mass lies within the dimensions of the spec-

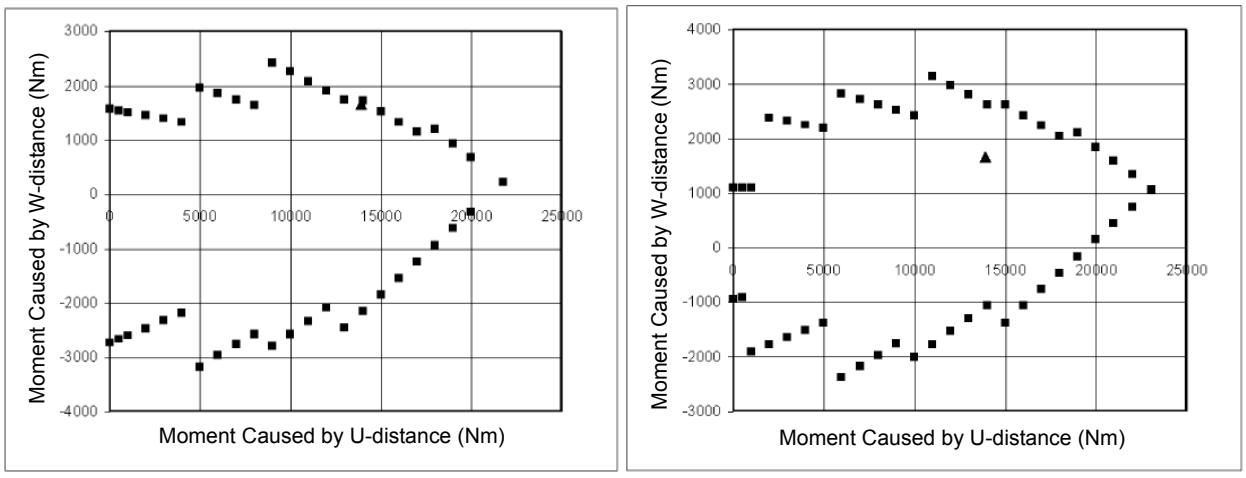
ified envelope. Two envelopes are specified based upon the assumed weight of the science instrument counter-weight rack of 150 kg (330.7 lbs) nominal or 100 kg (220.5 lbs). The operations center of gravity envelope is specified as along the V and W axes. A cone shaped by these figures defines the operational c.g. envelope for all science instruments (see Figure 2-14 and Figure 2-15).


Moment Caused by V-distance (Nm)
Moment Caused by U-distance (Nm)
Moment Caused by V-distance (Nm)
Moment Caused by U-distance (Nm)

Mass of SI Rack = 150 kg

Mass of SI Rack = 150 kg

Figure 2-14. The Maximum Moments Caused by Cg-Variations In the V-Direction


Moment Caused by W-distance (Nm)
Moment Caused by U-distance (Nm)
Moment Caused by W-distance (Nm)
Moment Caused by U-distance (Nm)

Mass of SI Rack = 150 kg

Mass of SI Rack = 150 kg

Figure 2-15. The Maximum Moments Caused by Cg-Variations In the W-Direction

Science instruments that use cryogenic liquids to cool their instruments are expected to produce changes in instrument mass during the flight as a result of cryogen boil-off. The telescope's active balance subsystem is designed to accommodate nominal changes in instrument mass and a result-

ant change in instrument moment around the cross elevation, line-of-sight, and elevation axes. The limits in changes of instrument moments are specified in the TA_SI_02 document.

4.3 Science Instrument Flange Pressure Boundary

The pressure boundary between the aircraft cabin and the telescope cavity is established through the mechanical interface between the science instrument and the telescope nasymth tube and gate valve. There are a number of possible pressure boundary configurations as illustrated in Figure 2-16.

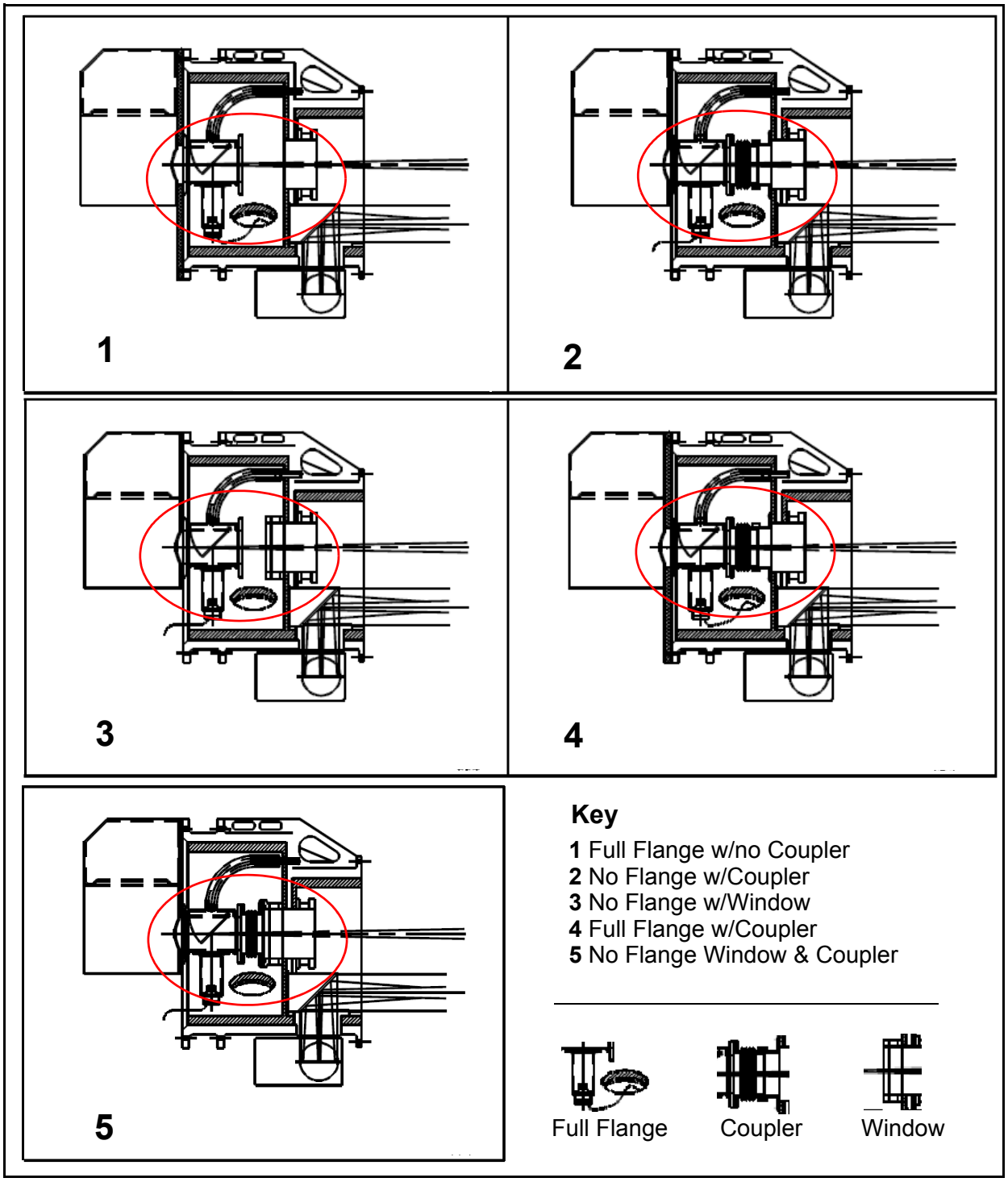


Figure 2-16. Pressure Boundary Configurations for Science Instruments

This figure illustrates five possible pressure boundary configurations for science instruments mated to the telescope instrument-mounting flange. The major mechanical components are the

full flange, the pressure coupler, and/or the gate valve window.

The pressure coupler connects the open (optical) port of the pressure window subassembly with science instruments that use only or additionally a small vacuum sealing interface diameter at the gate valve. The science instrument developer is expected to provide the required the pressure coupler. The pressure coupler shares the same interface to the telescope assembly as the optical window assembly. Some of the various pressure couple configurations have additional connection to the vacuum and/or the exhaust fittings/feed-thorough of the tub. When applicable, the differential pressure between the forward gate valve pressure plate volume and the aft volume causes the interface plane on the pressure plate to move along the U-axis. The pressure coupler between the science instrument and the gate value should necessarily accommodate these motions.

The concept of the optical window assembly is depicted schematically below. The figure shows a possible mounting of an optical window element. A typical assembly would be mounted to the flange assembly gate valve pressure plate using the same interface as the pressure coupler. The refractive, chromatical, etc. characteristics of the window material are likely to affect the focus and image quality of telescope system. The optical window assembly needs to withstand any loads caused by motions of the gate valve pressure plate under changing pressures. SOFIA will provide the optical window assembly.

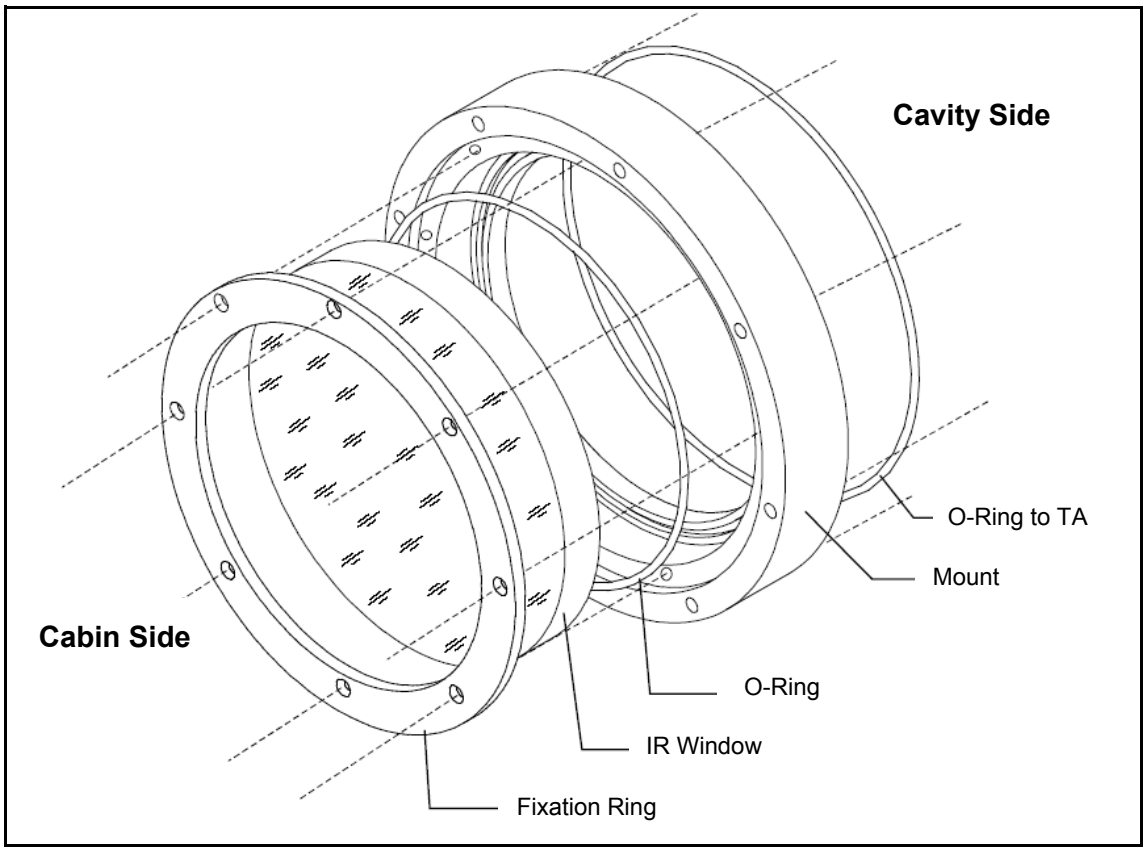


Figure 2-17. Example of an Optical Window Mounting Assembly

The fixation ring should not press directly on the window. An additional rubber gasket is required for a proper mounting.

Instrument developers should refer to the TA_SI_02 interface document for further discussion of vacuum fittings and access ports with the instrument mounting flange assembly. All landing/ crash, thermal convection/radiative loads are also specified in this original design document.

2.4.3 - Environment about the Science Instrument Flange

The electromagnetic field at the center of the instrument-mounting flange will be measured during system assembly, integration, and test verification. The recommended grounding practices for instruments are discussed in section 2.7.2 - ”Counterweight Rack” on page 2-45. The estimated power spectral density curves for in-flight telescope vibrations are given below. Final vibration levels will be available after SOFIA initial flight tests.

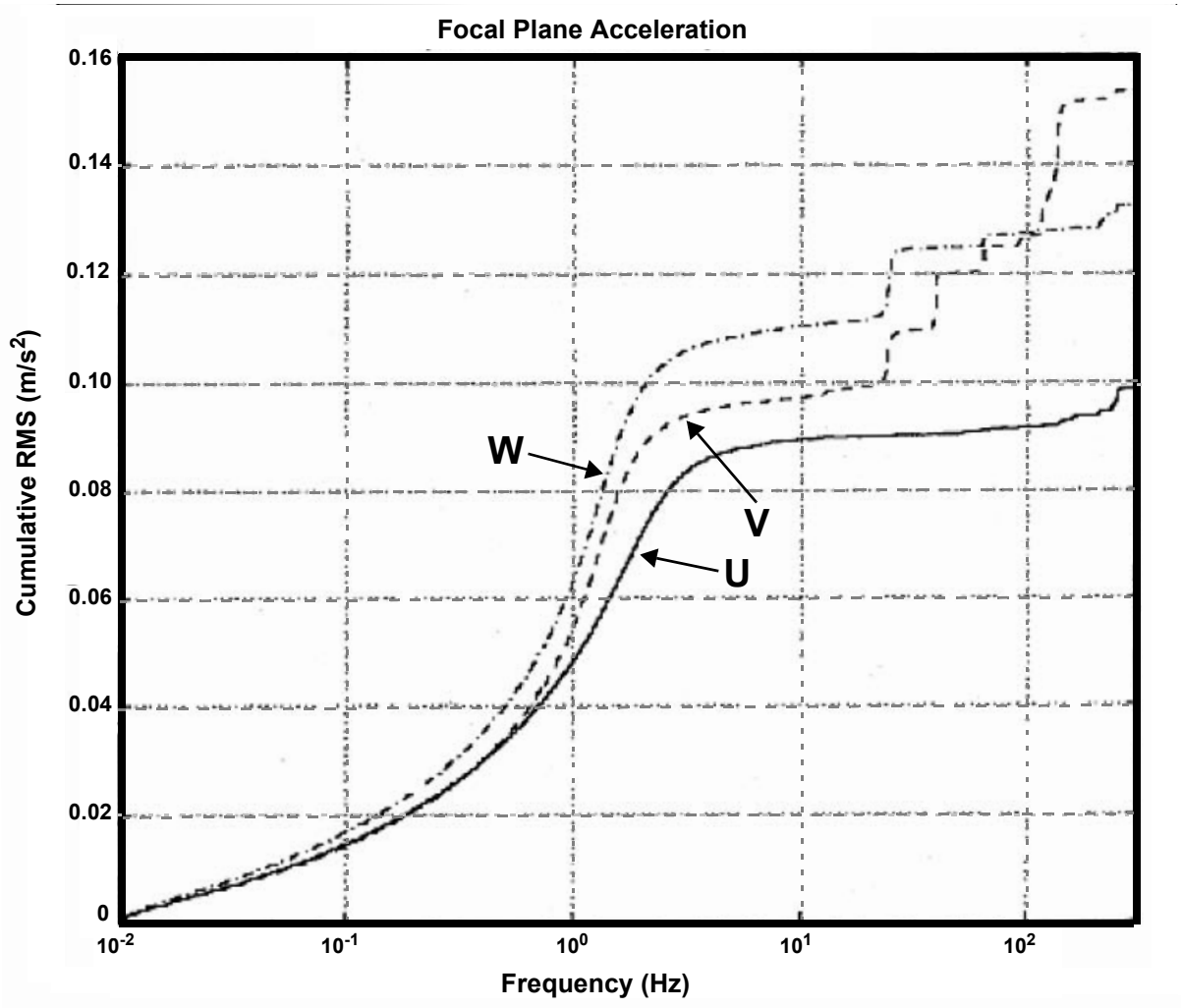


Figure 2-18. Science Instrument Accelerations in the U-, V-, and W- Directions

2.5 - Science Instrument Envelope

The SOFIA science instrument envelope controls the spatial interface with the aircraft and telescope. The interface control document Global 09 defined 3 envelopes that follow the science instrument installation process. During each of these phases, the telescope motions are specified. While mated to the telescope's science instrument flange, the science instrument volume begins at the vertical plan of the flange and extends forward. The science instrument volume also includes a volume segment that extend aft of the flange and fits within the telescope's Nasmyth tube (while not extending aft of the gate valve). The three science instrument envelopes are:

2.5.1 - The Installation Volume

The installation volume refers to the volume of the science instrument or subsystem during installation on the aircraft. This volume is also to include the science instrument installation cart. (See Figure 2-19) The installation envelope is defined by the volume suitable for moving through the aircraft doorway (i.e., the distance to the stairs when entering door 1L [see Figure 2-25]). The height of the envelope was established to allow clear viewing over the SI during travel through the facilities and the aircraft. The installation volume height allows the science instrument to roll along the installation cart path without interfering with overhead structures within the aircraft. Other aspects of the installation envelope are specified in Global 09.

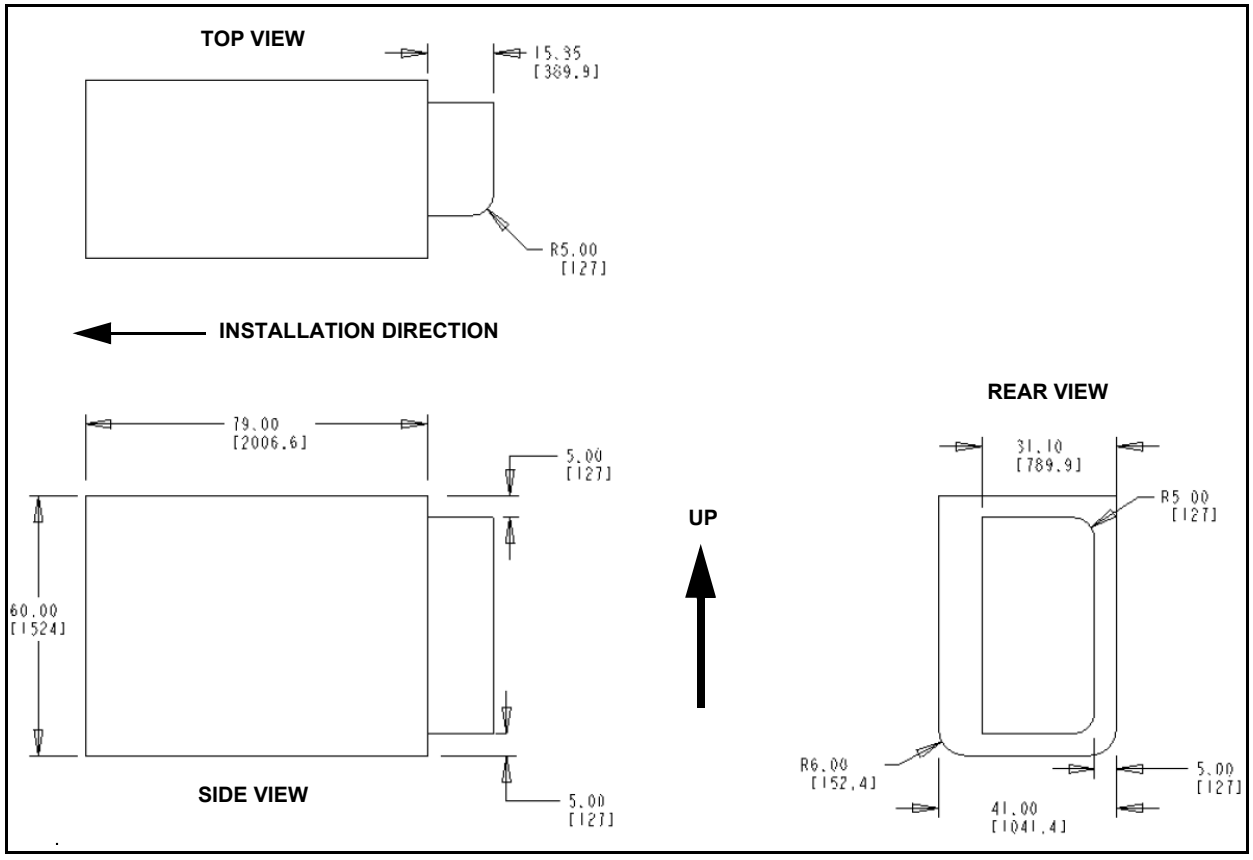


Figure 2-19. Science Instrument Installation Volume — 3-D Solid Modeling Drawing

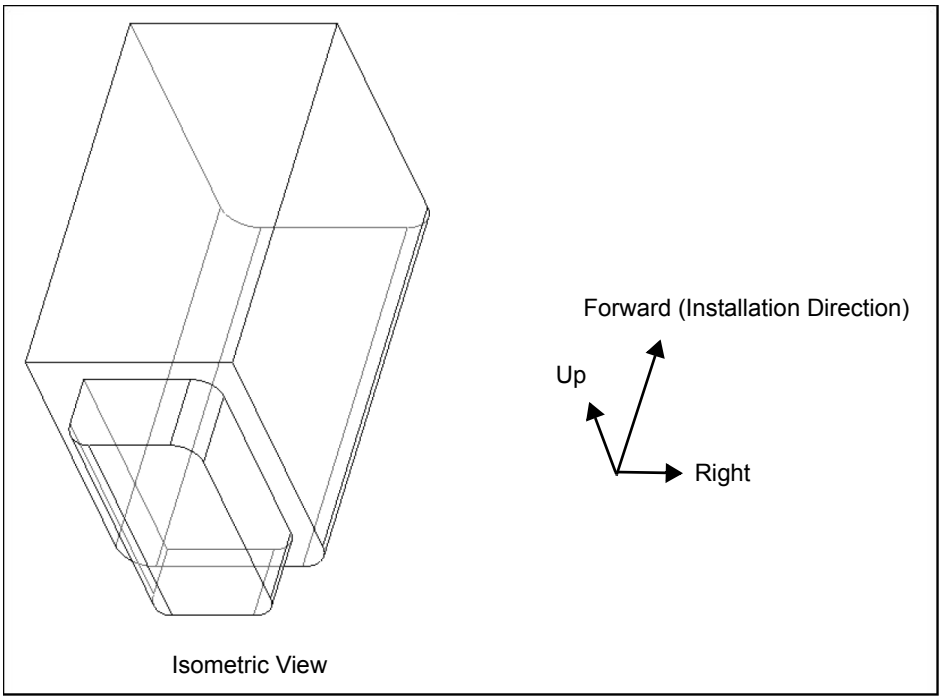


Figure 2-20. Science Instrument Static Serving Envelope — Isometric View

2.5.2 - Static Instrument Volume

The static instrument volume is also known as the 'stay-out-envelope'. Both the telescope and aircraft systems are to avoid this area. This volume includes space to allow the science instrument teams to work with and around the science instrument. During the science instrument installation phase, the telescope is expected to remain in a fixed position (typically at an elevation of 40º). The static instrument volume is based upon the location of the telescope's instrument flange but also includes the SI volume which is permitted to extend forward of the flange interface. (See Figure 2-21 and Figure 2-22.) The static envelope is fixed with respect to the aircraft structure.

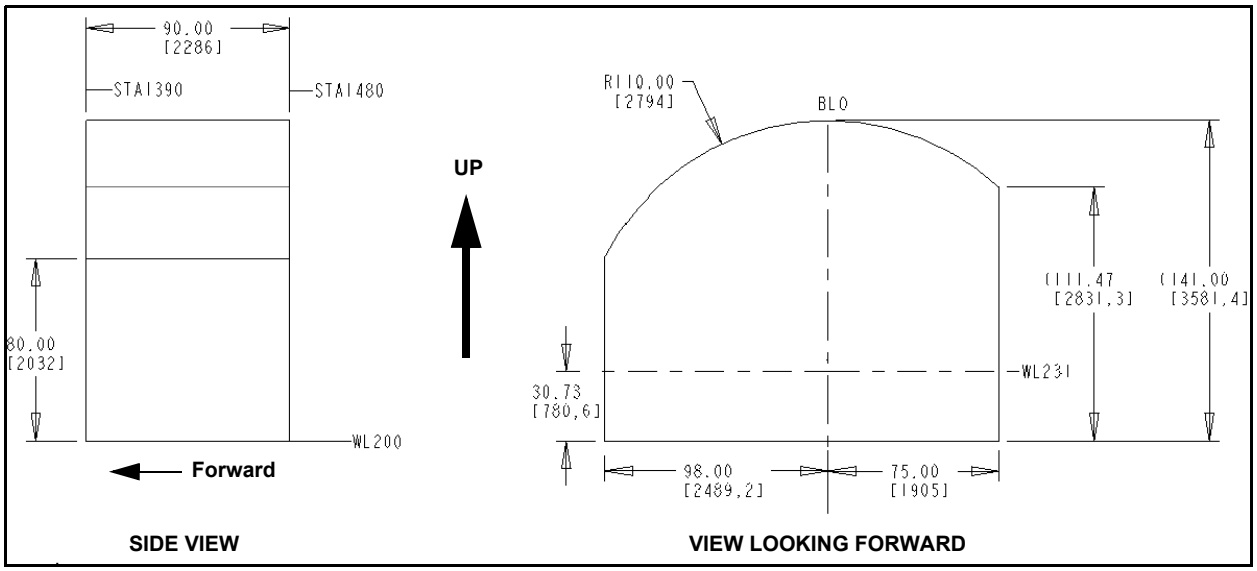


Figure 2-21. Science Instrument Static Servicing Envelope — Side And Rear Views

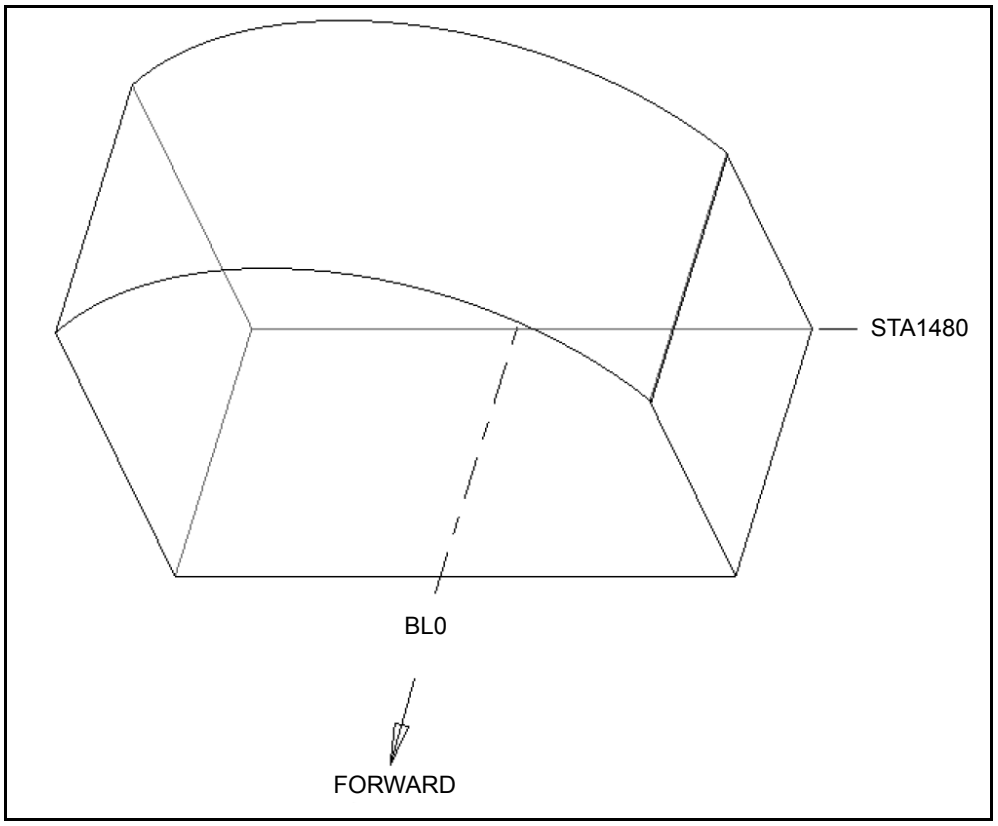


Figure 2-22. Science Instrument Static Serving Envelope — Isometric 3-D View

2.5.3 - Dynamic Instrument Volume

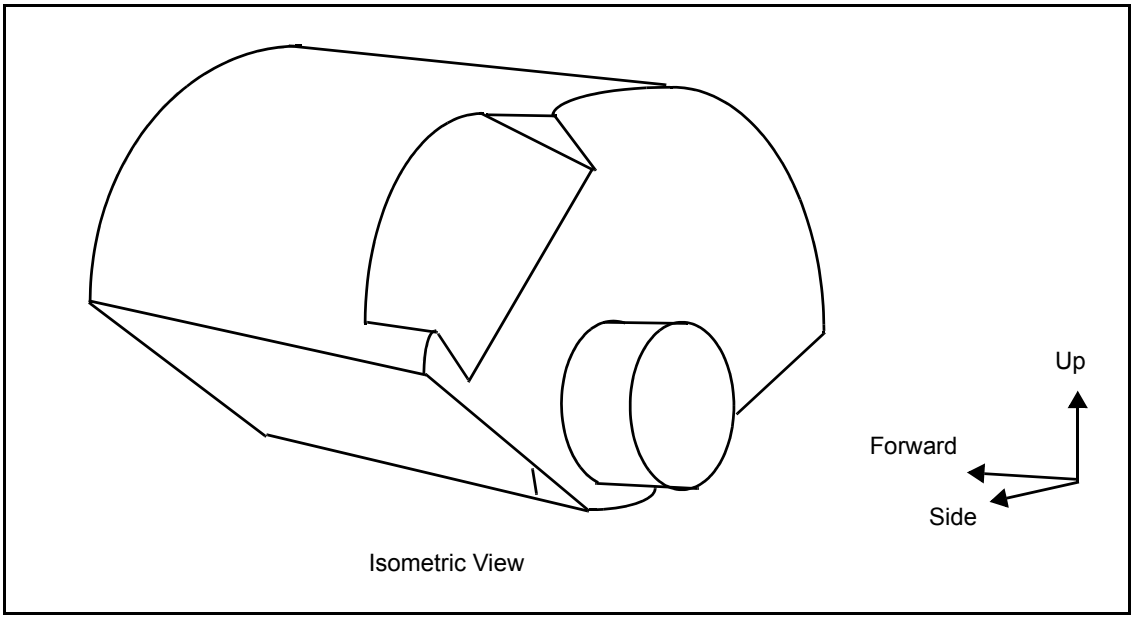


Figure 2-23. Science Instrument Dynamic Envelope — Isometric 3-D View

This envelope is the stay-in volume for the science instruments such that motions of the telescope assembly (e.g. changes in telescope elevations) do not cause the science instrument to interfere with stationary objects within the aircraft. The expected range of telescope motions is dictated by normal telescope operations while the observatory is airborne (see Figure 2-24). The dynamic envelope is derived from the complete range of possible telescope motions during normal flight operations. These are based on the ranges of motion the telescope can go through when uncaged as stated in the Global 09 document. For generation of the envelope it was required that no science instrument component could come within 4 inches of any aircraft structure (i.e., floor, ceiling, etc.). The dynamic envelope was developed assuming the telescope in its worst-case condition of being tilted toward the aircraft floor. In this position, the telescope was run through its full range of operational motions about the U-axis. Material was added or subtracted from the SI volume to maintain the 4-inch margin with respect to the aircraft. A 45 ° cutout in the aft section of the volume accounts for struts that support the science instrument counter weight rack (see TA_SI_05). A protrusion centered on the infrared optical axis of the telescope and forward of the science instrument flange is to accommodate a science instrument rotator (often used in polarimetric instruments). The dynamic envelope is fixed relative to the telescope and science instrument coordinate system.

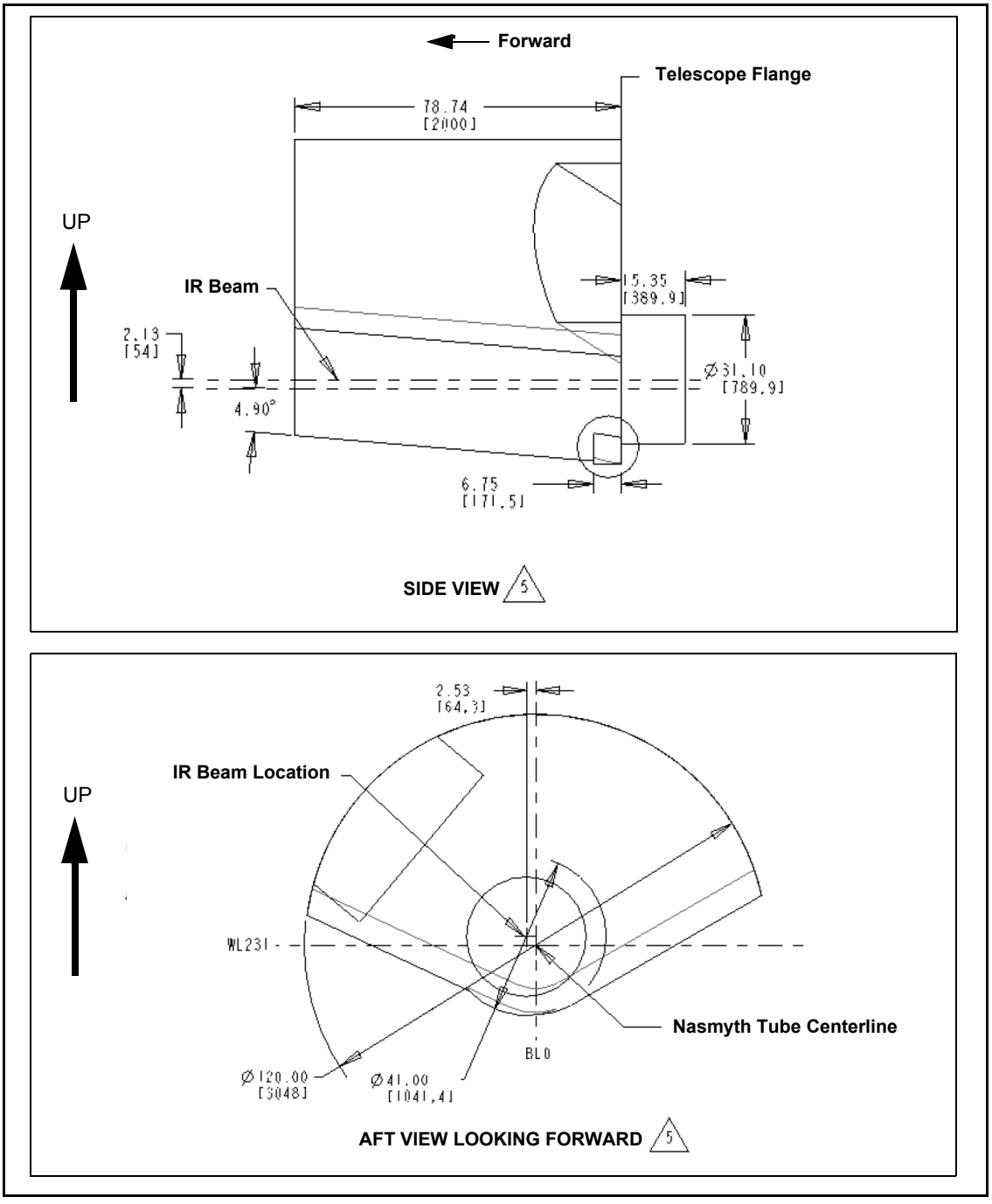


Figure 2-24. Science Instrument Dynamic Envelope

Side And Rear Views With Telescope At The Nominal Installation Elevation

2.6 - Science Instrument Cart

A cart is used to transport a maximum payload of 600 kg (1320 lbs) [science instruments and other equipment] through the ground facility, up to the aircraft, through the passenger door, into the main deck passenger compartment, and up to the telescope science instrument flange. Two interface control documents – ICD SIC_SI_01 [96162511] and SIC_AC_01 [96162512] – describe the engineering requirement for instruments planning to use the USRA provided instrument cart (SIC_SI_01) or the requirements for instruments planning to deploy their own carts (SIC_AC_01). Developers should consult the original documentation for specific engineering requirements. In general, science instrument carts must meet the following requirements:

a. The loaded cart shall be able to maneuver through constructed passageways such as the 1L passenger door and along the SI cart path. As mentioned previously, the science instrument cart needs to fit within the installation envelope specified by Global 09. Depending upon the cart length, the successful design may require swiveling casters at all wheel locations.

b. The loaded cart shall be able to negotiate 1:20 ramps with all wheels maintaining contact with the floor. Maintaining contact with the floor at all times may require a suspension system. Any system employed, however, must be designed to distribute the cart weight so that the load per wheel does not exceed the maximum allowable load per wheel.

c. The loaded cart shall not damage the aircraft floor structure by its usage. Aircraft floor panels limit the loads that can be safely transported aboard the SOFIA aircraft. Panels along the science instrument installation path have been upgraded to withstand science instrument installation traffic. Details of the maximum wheel load and the dimensions of the allowable center of gravity zones for various science instrument installation weights are contained within SIC_AC_01.

d. The loaded cart shall not apply any loads on the reveal lip surrounding door 1L. The USRA team is expected to provide access ramps that protect the reveal lip of the aircraft when correctly installed.

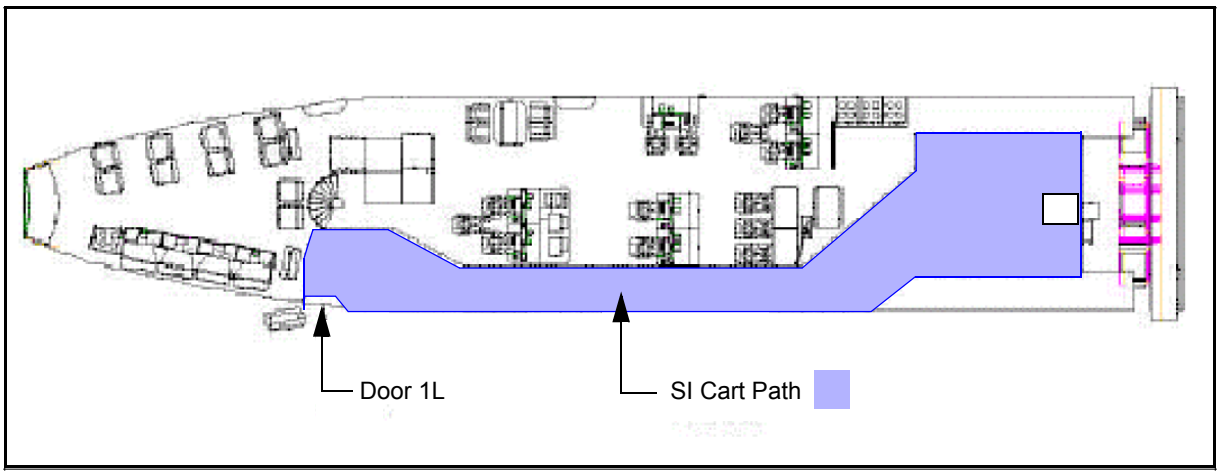


Figure 2-25. Science Instrument Cart Path

The hatched areas correspond to reinforced floor panels required to support the maximum allowed weight of SOFIA science instruments. A large section forward to the telescope flange is reinforced to allowing 'staging' of multiple science instruments.

Instrument teams are cautioned that exceeding the instrument cart wheel design load capacity or operating the cart outside of the intended cart path will result in floor panel damage and cause cart instability leading to personnel injury or damage to science instruments. All science instrument carts must be loaded in a manner that will ensure that no wheel carries more than the weight specified by the existing interface control documents.

In addition, science instrument carts shall have wheels with the following safety features:

a. Wheels shall have the ability to be locked in a manner that prevents any unwanted translation. Casters shall be locked and restrained with retainers when the cart is not being moved.
b. Swiveling casters shall have the ability to lock into fixed, angular positions (a beneficial feature when moving through narrow passageways).
Due to the heavy nature of some science instruments, instrument teams should take great care when maneuvering a loaded science instrument cart. The following precautions should be followed at all times when transporting instruments throughout the SSMOC and SOFIA aircrafts:

a. There shall be sufficient personnel controlling the cart so that no one person must exert unsafe levels of force.
b. Caution must be used when ascending and descending aircraft access ramps to maintain control of the cart.
c. Science instrument shall be mounted in a stable position so as to minimize the risk of tipping.
d. When at all possible, the cart should be pushed from the short side so as to minimize the risk of tripping. Great care should be exercised when pushing the long side of the cart.

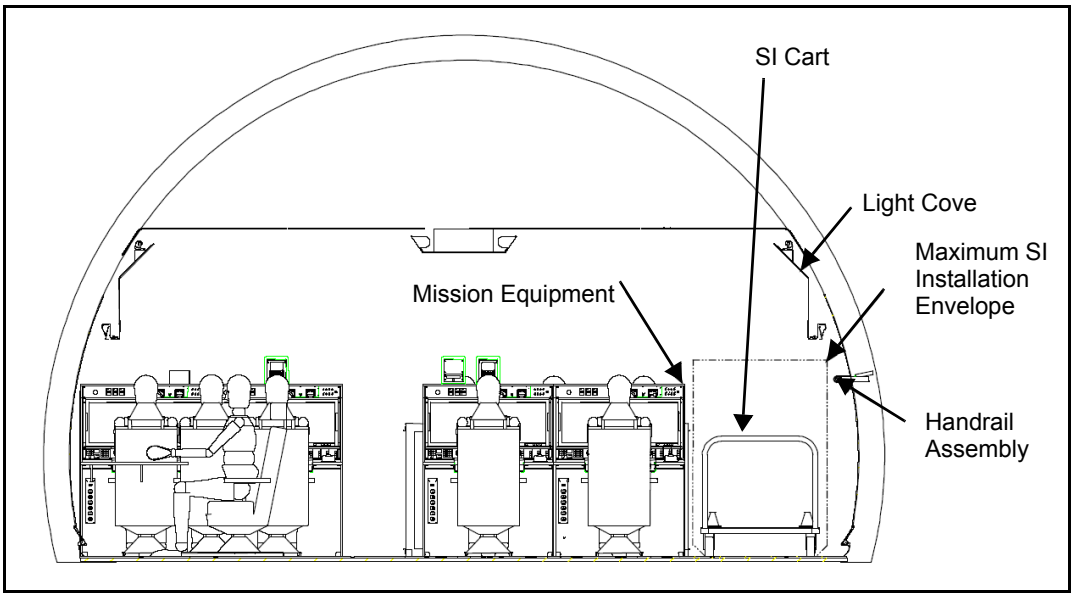


Figure 2-26. Science Instrument Cart Positioned On Cart Path

Developers should note that the maximum science instrument cart footprint is constrained by the dimensions of the 1L aircraft door. As specified in Global 09, the 'flat' portion of the aircraft door is approximately 31 inches in length. The maximum cart footprint width should therefore be approximately 30 inches as shown in Figure 2-28.

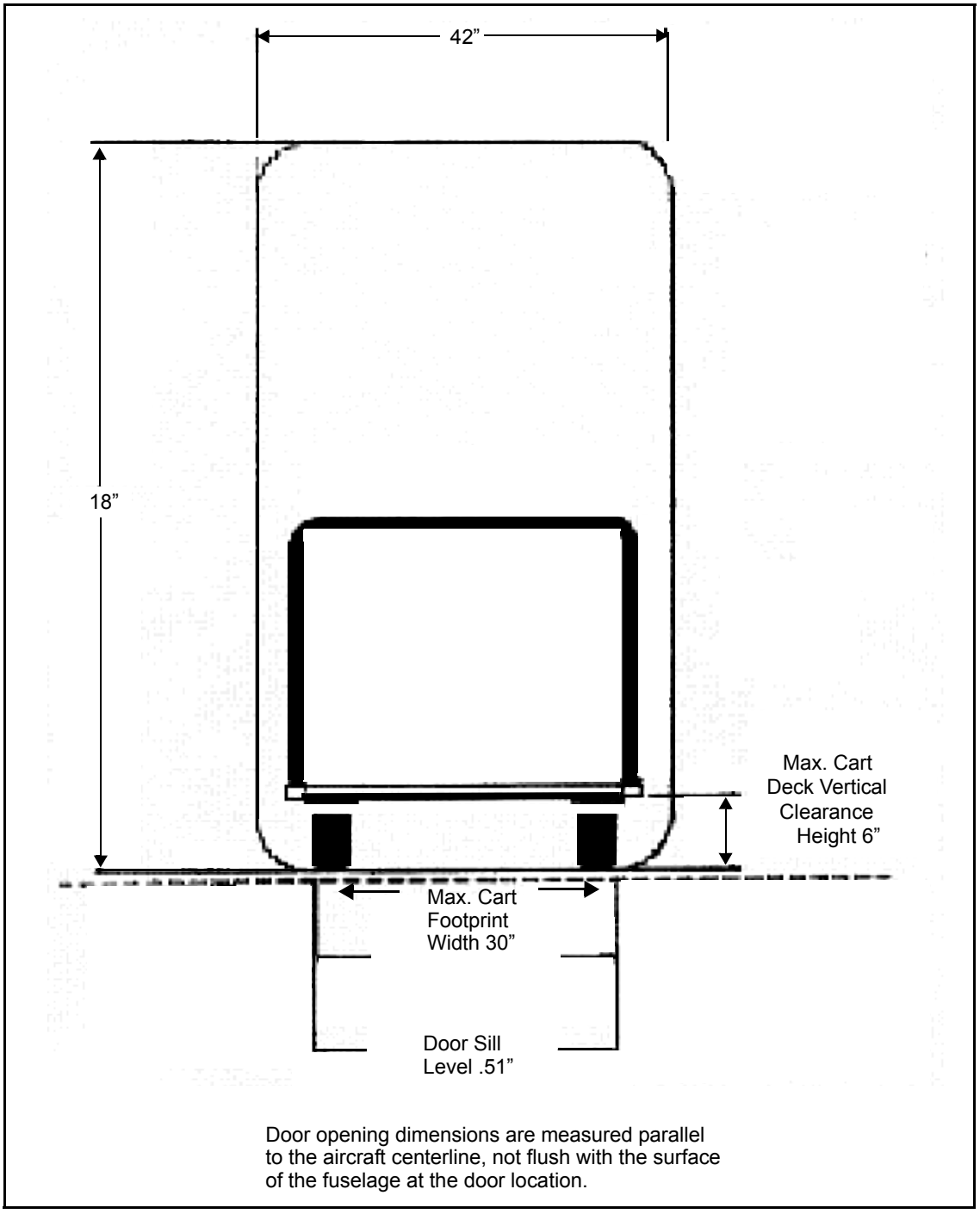


Figure 2-27. Example of the Maximum Science Instrument Cart Footprint Width allowed by SOFIA

This figure does not show the overlap of the fully opened passenger door with the aircraft door opening – only the aircraft door opening is shown.

A sample science instrument cart is illustrated below in Figure 2-28. The USRA provided cart contains several features that accommodate a great many science instrument designs. The cart is primarily designed to withstand the severe loads associated with the maximal weight limit of science instruments. The cart allows one to adapt to any of the SI in need of transportation. The table dimensions of 60 inches by 36 inches allows the cart to safely handle the largest instruments, yet are small enough to make maneuvering the other science instruments less cumbersome. Seat tracks have been incorporated on the top of the cart to allow for many different mounting fasteners to be used in many different mounting locations. The cart also allows for the safe distribution of loading across the aircraft floor panels. With such a design, it is imperative that the center of gravity be located in a predefined zone as discussed in the ICD SIC_AC_01. An efficient and economical design will allow the science instrument to be wheeled directly from the SSMOC to the telescope and not require extensive vertical adjustments. The center of the telescope science instrument flange is specified as 841.5 mm (33.13) inches and should be within ± 0.3 ° of vertical.

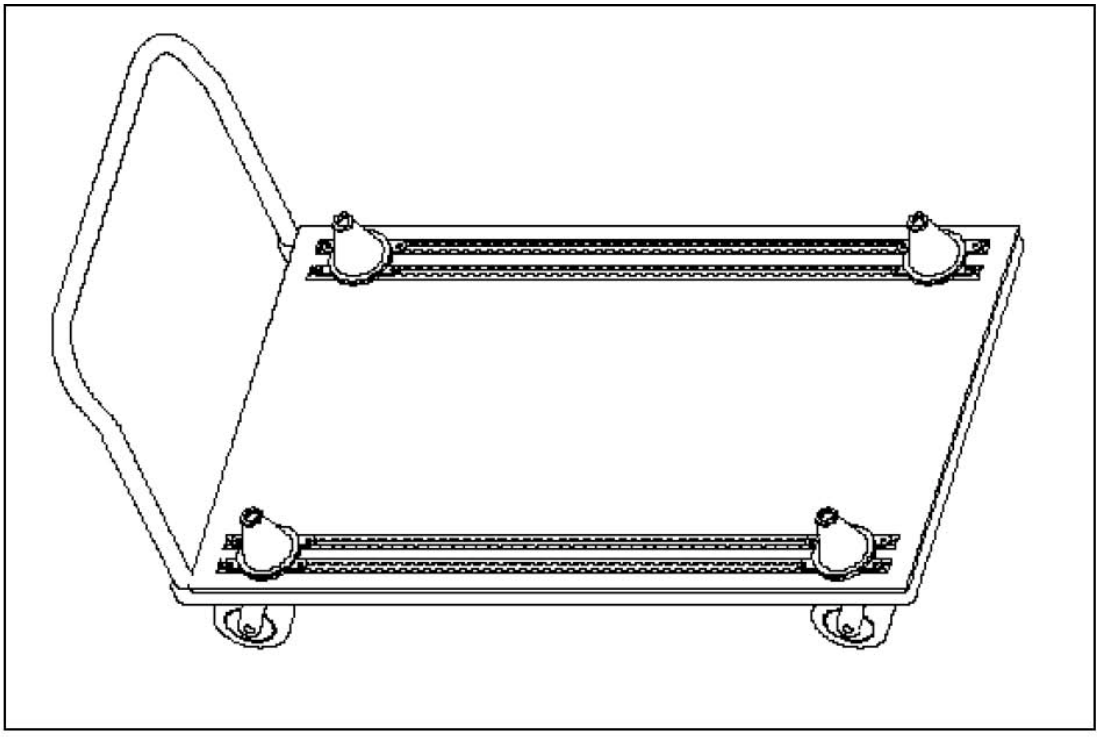


Figure 2-28. USRA Provided Science Instrument Cart

This isometric figure shows a sample cart design suitable for use aboard SOFIA.

2.7 - Instrument Racks (PI Rack)

The USRA program will provide science instrument teams with a number of electronic racks certified for aircraft use and designed for installation aboard SOFIA. A principal investigator (PI rack) is for electronics and computers needed within the immediate seating location of instrument teams. A second rack mounted forward to the telescope's counter-weight assembly is for instrument electronics located a short distance from the science instrument itself. Schematics of both racks are available to instrument teams who desire to construct their own flight hardware. The SOFIA Facility librarian has detailed drawings for these racks and copies will be sent upon request.

2.7.1 - PI Rack

An instrument rack specifically designed for use on the SOFIA is shown in Figure 2-29. It accepts standard 19-inch wide front panels with packaged electronics attached. Pertinent dimensions are shown in Figure 2-30. These racks are made available to all Investigators and must be used instead of conventional laboratory instrument racks. The completed rack of equipment is bolted to a fixed frame on the aircraft floor on existing seat rails, as shown in Figure 2-31. If additional racks are necessary, they may be fastened to seat-tracks in the cabin floor.

The recommended procedure in assembling an instrument rack is to first prepare a preliminary scale layout of the equipment in the rack, taking into account the loading and moments data provided starting with Figure 2-30 and going to Figure 2-36, and Table 2-2 and Table 2-3. A list of components must also be prepared, including weights and locations. Use Worksheet 2-1 - "Instrument Rack Weight Sheet" on page 2-45 to assist preparation. Based on the scale layout and the worksheet, the cognizant USRA SOFIA engineer will check the loading and moments to determine if they are properly distributed within the rack. Specially designed support trays are available for heavier components. The SOFIA staff will provide assistance in properly loading the instrument racks and will perform the installation of loaded racks onto the aircraft.

Instruments may be installed facing forward or aft, but note that the forward side of the rack faces the Investigator seating and the aft side faces the telescope and PI cabling patch panel. Some instruments may also be attached to the top of the rack using appropriate straps, rails or plates, provided these components also satisfy the relevant safe loading criteria. Bending, cutting, drilling, etc. may not modify an instrument rack, without prior written approval of the SOFIA Airworthiness Assurance Office.

Television monitors are available for mounting in or on top of the Investigator's instrument rack. These may be used to display any of the camera fields or the housekeeping video display. The choices include a large monitor (l3-inch diagonal screen, two video inputs) for mounting on top of the rack, or a chassis containing three small monitors for mounting in the rack. Each monitor in the latter unit has a 5-inch diagonal screen and a separate single video input. Other SOFIA facil-

ity-supplied equipment available from USRA includes 110V power distribution panels, an 8-channel strip-chart recorder and a storage cabinet. Relevant physical dimensions of these items are given in Table 2-2.

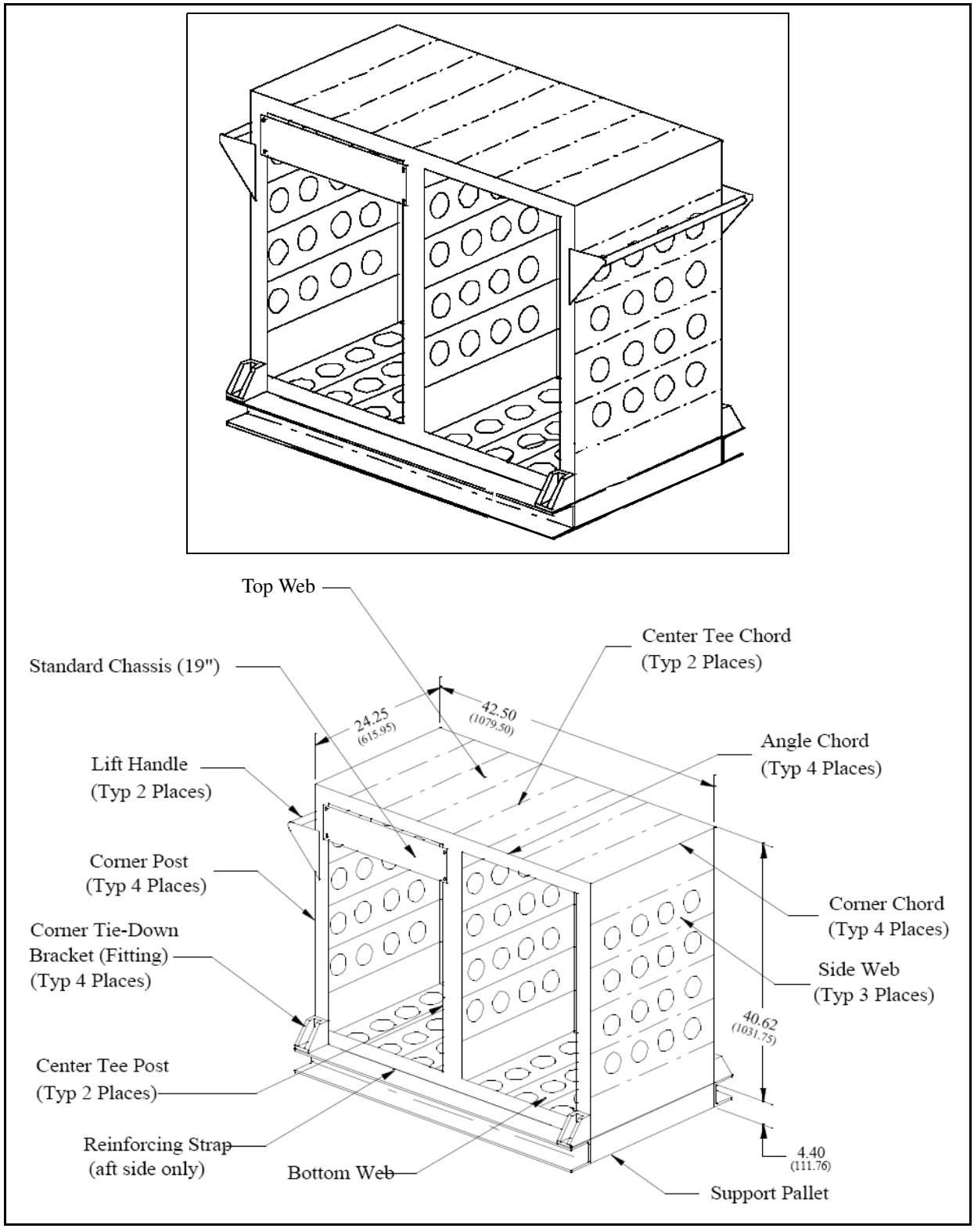


Figure 2-29. SOFIA Standard Instrument Rack

An optional utility drawer/keyboard tray is installed in the left bay, and a heavy chassis support tray is installed in the right bay. Cable chafing guards are installed in some of the lightening holes (e.g. bottom center). Equipment may be also mounted on the top surface, provided the weight and moment constraints are satisfied.

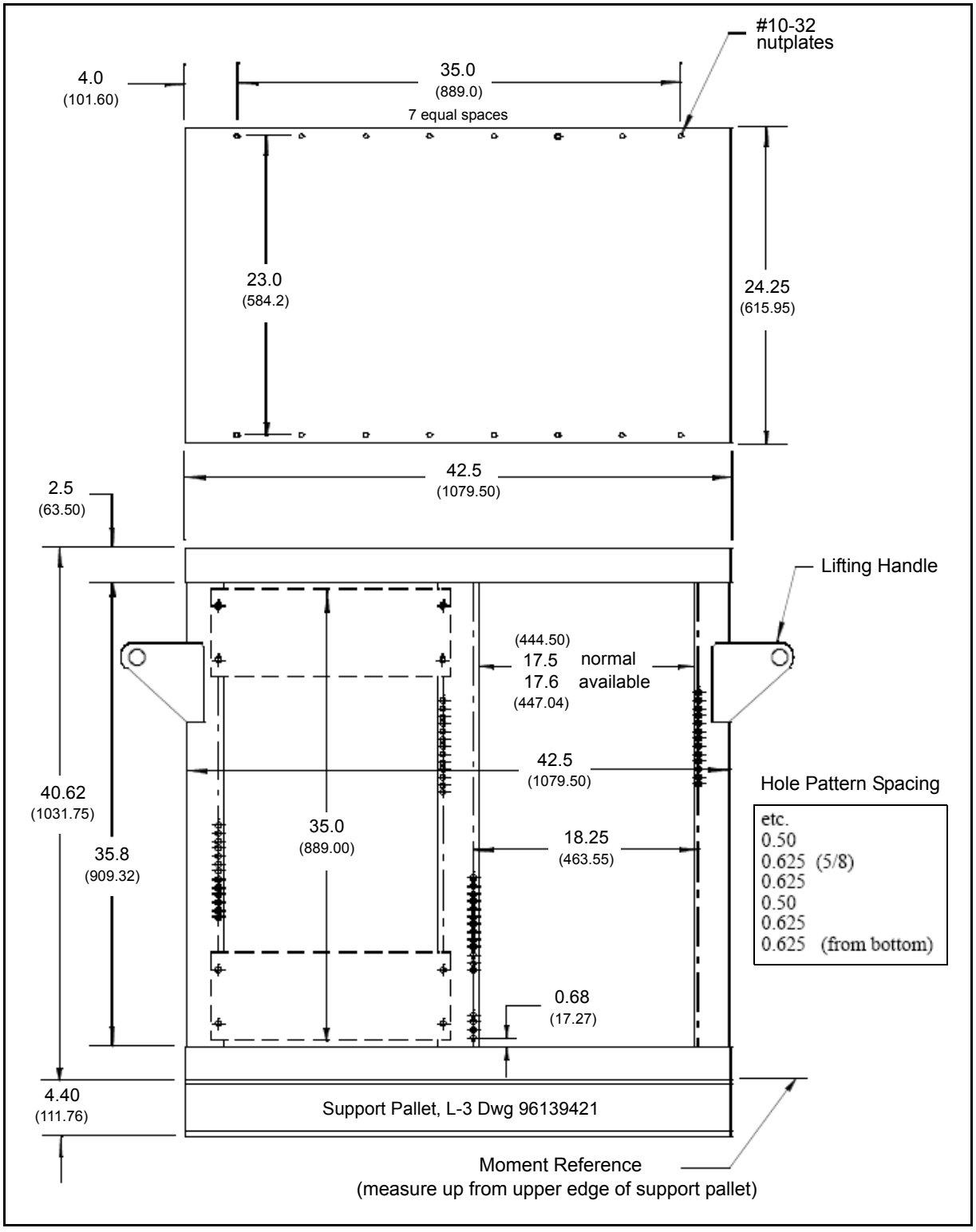


Figure 2-30. Standard Instrument Rack Dimensions

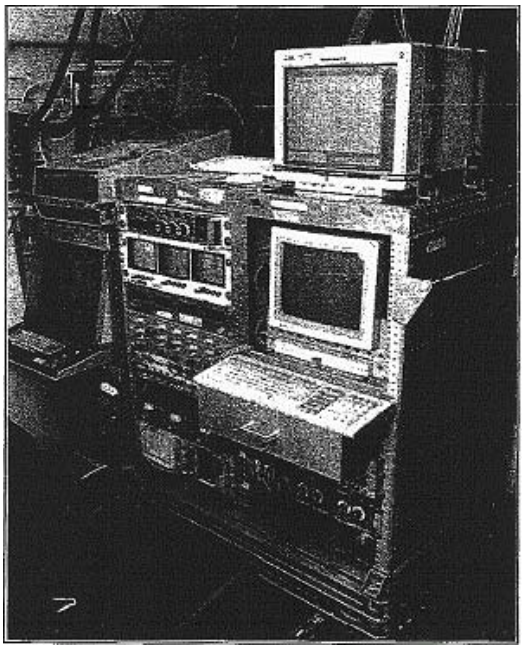


Figure 2-31. A Typical SOFIA Instrument Rack

****** COMMENT *** need a new figure with flat panels***

Moveable items such as the keyboards, mouse, and utility drawer seen here are stowed for takeoff and landing.

Table 2-2. Facility Supplied Rack Equipment

Item	Weight	Height	Depth
110V power distribution panel	3.17 kg (7 lbs)	127 mm (5.0 in.)	76.2 mm (3.0 in.)
Utility drawer/keyboard try	9.98 kg (22 lbs)	88.9 mm (3.5 in.)	469.9 mm (18.5 in.)
Heavy chassis support tray	2.72 kg (6 lbs)	25.4 mm (1.0 in.)	614.68 mm (24.2 in.)
Intercom multiplier box	2.72 kg (6 lbs)	44.45 mm (1.75 in.)	196.85 mm (7.75 in.)
19-inch B&W TV monitor *	19.05 kg (42 lbs)	279.4 mm (11.0 in.)	431.8 mm (17.0 in.)
9-inch B&W TV monitor 8	4.98 kg (11 lbs)	226.6 mm (9.0 in.)	279.4 mm (11.0 in.)
Set of 3 small TV monitors	16.32 kg (36 lbs)	304.8 mm (12.0 in.)	177.8 mm (7.0 in.)
8-channel strip-chart 8	36.29 kg (80 lbs)	406.4 mm (16.0 in.)	254 mm (10.0 in.)
Storage cabinet	3.18 kg (7 lbs)	266.7 mm (10.5 in.)	304.8 mm (12.0 in.)
*Usually mounted on top of the rack			

The depth values listed above do not include clearance needed by chassis for cabling. The utility drawer and the support trays use mounting holes at both the front and back of the bay. The 110V power distribution panel is described elsewhere. The SOFIA Facility Manager should be contacted for help with any unusual problems encountered in mounting equipment in the rack or if any components are not compatible.

Two effects must be considered in planning the installation of equipment into the deck. First, the overall effect of the rack load on the aircraft floor and attachment points requires a reasonable distribution of the load over the floor area and a low center of gravity. Second, the localized effect of components of various weights in the rack will determine the mounting hardware required to handle aircraft deceleration loading on the rack structure.

The total equipment load allowable on the standard two-bay rack is 270 kg (600 lbs). If the total weight approaches this limit, the equipment should be arranged m the rack so that the weight is distributed fairly evenly among the four rack sections, as shown in Figure 2-32. However, this distribution can vary provided that the total weight for any two sections does not exceed 7620 kg (300 lbs).

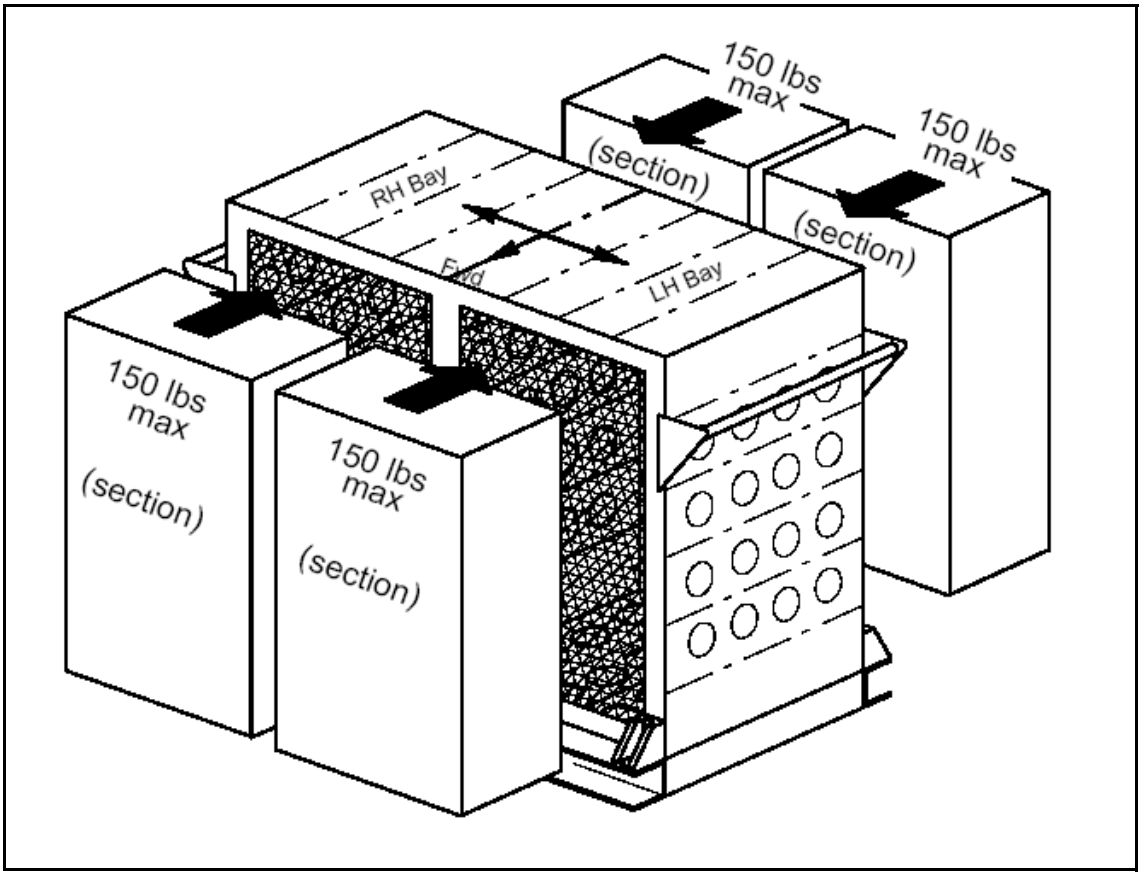


Figure 2-32. Equal Maximum Weight Load in 4 Rack Sections

If possible, the heaviest item should be located near the bottom of the rack to keep the total overturning moment of the rack as low as possible. The sum of the torque moments produced by the installed equipment, as defined in Figure 2-33, must not exceed 1000 ft-lb**.**

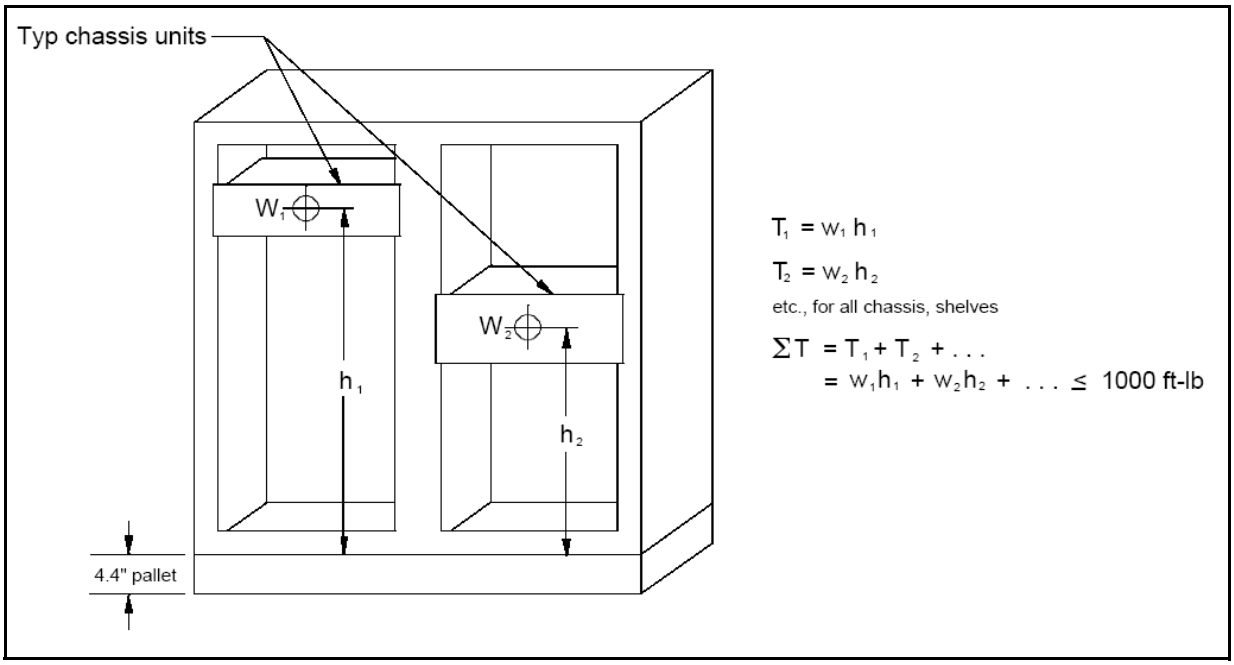


Figure 2-33. Calculation of Rack Torque Moment

USRA and the FAA require safety factors in panel loading to handle 6.0 g vertical loading and 9 g forward deceleration. A heavy chassis may require a supporting tray. Table 2-3 provides examples of maximum chassis weight as a function of front panel height. As shown in the table, the weight limits are somewhat different for the two sides of the rack. Table 2-3 shows the larger weight limits that use of supporting trays provide.

Table 2-3. Maximum Chassis Weights

Max. Allowed Weight W (lbs)					
Front Panel					
Standard Height	Max. Allowed Moment	(FWD side of rack		(AFT side of rack)	
		no	with	no	
(inches)	M (ft-lb)	tray	tray	tray	with tray
3.5	7	23 lb	35 lb	35 lb	45.5 lb
5.25	9.3	26	45	52	63
7	14	35	54	67	80.5
8.75	18.7	43	62	87	98
10.5	23.4	52	71	105	115.5
12.25	28	61	80	122	133
14	32.8	70	89	140	151

Notes:

- The actual moment at point B is M = W * L, where point B and distance L are defined in Figure 2-33.
- The allowable moment M at point B includes a 6.0 g down factor.
- The maximum allowable weight W at the c.g. includes a 9.0 g forward load factor.
- Weight limits with tray assume no equipment mounted directly in line on opposite side of rack.
- If a tray is used, the moment limit M can be disregarded.
- For ease of handling, a tray is recommended when the chassis weighs 50 lb. or more.

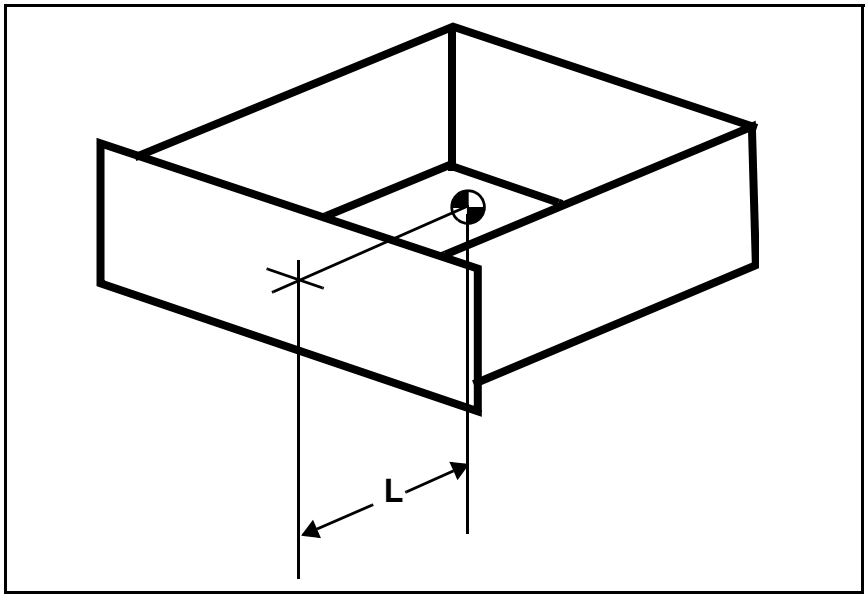


Figure 2-34. Location and Depth L of Chassis Center of Gravity

WORKSHEET 2-1. Instrument Rack Weight Sheet

SOFIA INSTRUMENT RACK WEIGHT SHEET **Date:** _____

Serial No: _____

Max Total Weight 600 lb., Max. Weight each bay 300 lb, Max. Moment:12000 in-lb.

	LEFT BAY ITEM (or top surface)	**WEIGHT W** (pounds)	**ARM H** (inches)	**MOMENT** WH (in-lb)
1:				
2:				
3:				
4:				
5:				
6:				
7:				
8:				
9:				
10:				
	TOTALS:			

	RIGHT BAY ITEM (or top surface)	**WEIGHT W** (pounds)	**ARM H** (inches)	**MOMENT** WH (in-lb)
1:				
2:				
3:				
4:				
5:				
6:				
7:				
8:				
9:				
10:				
	TOTALS:			

2.7.2 - Counterweight Rack

In addition to the mounting instrument electronics with the SOFIA Principal Investigator (PI) rack or within the dynamic instrument envelope, science instrument teams can also mount instrument

electronics to the forward surface of the telescope assembly counterweight plate. USRA has designed the Counterweight Rack (CWR) to mate to existing telescope hardware. The CWR can support between 100 and 150 kg of science instrument equipment. USRA will provide the SOFIA instrument program with two counterweight racks and made available at the SOFIA Science and Missions Operations Center (SSMOC). Science instrument teams, in need of their own rack, can order needed hardware through USRA. The counterweight rack will be mounted as required by SI teams. If the CWR is not required, telescope assembly counterweights will be installed utilizing the same mounting points and locations as the CWR. Instrument teams should note that use of the USRA CWR might result in degradations in telescope pointing performance beyond nominal limits. All cabling for electronics with the CWR must meet the interface requirements stated in TA_SI_01. Science instrument teams shall provide any vibration isolation as needed by their equipment.

An installed CWR is shown in Figure 2-36. The CWR is typically mounted before the science instruments using a cart and lifting device provided by USRA. The CWR will be equipped with lifting fixtures for mounting and ground handling. The CWR is attached to the telescope counterweight plate through bolts and fixed nut plates on the rack structure.

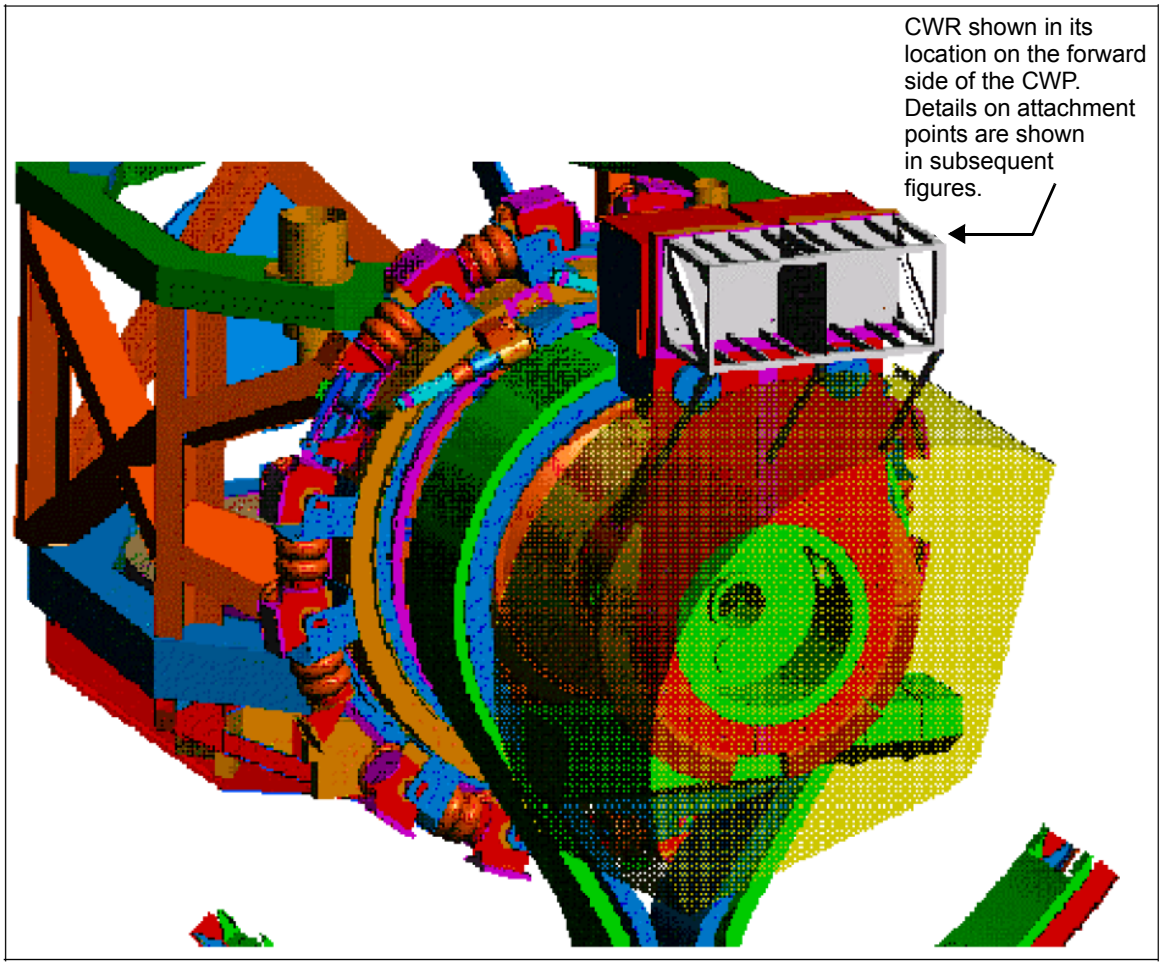


Figure 2-35. Science Instrument Counterweight Rack

The telescope points toward the zenith. The yellow shaded volume represents the dynamic science instrument volume required by in-flight operation of the telescope.

The rack itself is electrically isolated from the telescope assembly. A ground termination stud is available and shall be made to at least one of the following ground sources:

a. The ground terminal strip on the SI power panel.
b. The ground stud on the SI patch panel.
c. The science instrument
d. The telescope assembly.

Wiring for grounding of the CWR will be provided by the SSMOC facility engineering staff for connections to either the SI parch panel of the SI power panel. SI developers are responsible for other desired grounding connections. Since the USRA provided CWR is an open truss structure, installed instrument components will require enclosures and shielding for electrical and airworthi-

ness requirements. As expected, all CWR equipment must satisfy the same FAA EMI requirements as any other SI components.

All the design requirements of the science instrument counterweight rack are contained in the interface control document TA_SI_05. Interface details of the counterweight rack as design by USRA are contained in the "Science Instrument Equipment to Counterweight Rack" ICD. The CWR to SI ICD includes the physical dimensions of the payload envelope, center of gravity limits, maximum interface loads, attachment point locations, and recommendations for mission assurance. The SI developer must include a complete analysis, to be submitted for DER approach, detailing SI electronics airworthiness and calculations displaying that the interface loads are within the constraints specified.

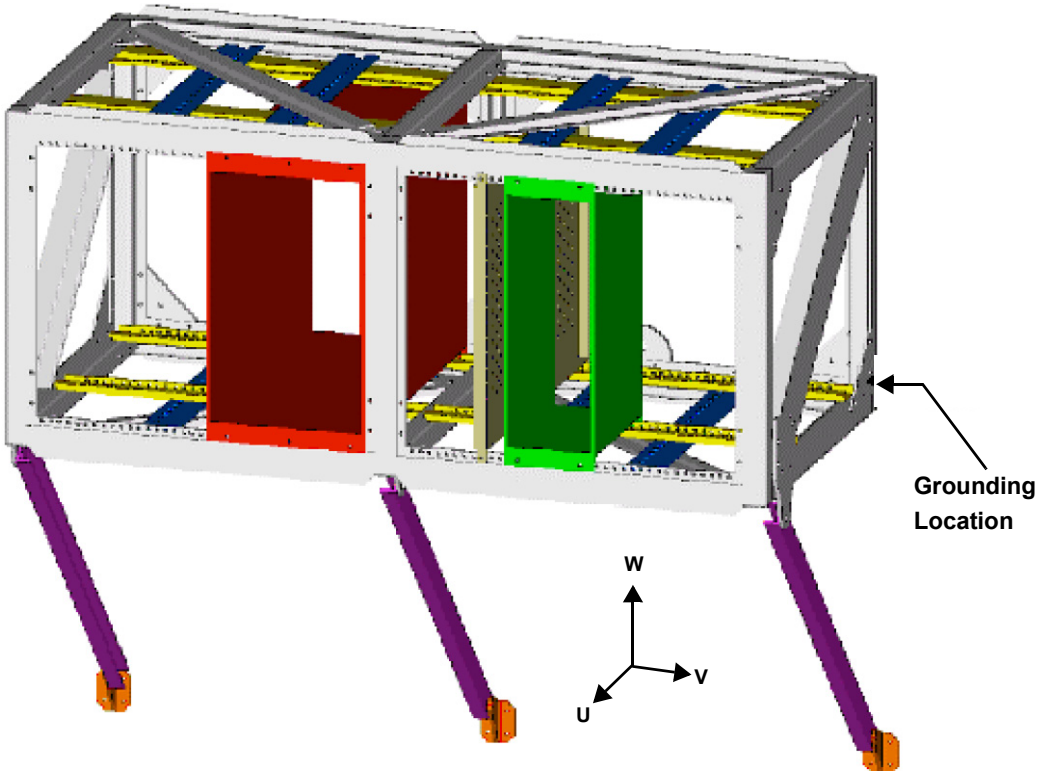


Figure 2-36. Science Instrument Counterweight Rack Showing Grounding Location

Isometric view of the science instrument counterweight rack displays a grounding location and an example of equipment mounting scheme.

2.8 - Instrument Cabling Patch Panels

The observatory provides for installation and operation of up to three PI equipment racks containing electronic equipment use to gather, process, and analyze scientific astronomical data. The

SOFIA instrument racks are interfaced to one another and other instrument subsystems (e.g. the telescope secondary mirror controller, telescope gyroscopic readouts, or the USRA provided mission control software) through cable assemblies provide by instrument teams, USRA, and NASA government furnished equipment. Access to much of the aircraft cabling is accessed through one of several patch panels provided throughout the observatory. Cabling patch panels are available in several locations – aft of the PI instrument rack, on the port side of the aircraft near the telescope's pressure bulkhead, and on the telescope counter weight assembly. The details of the patch panels are described in several documents:

a. MCCS_SI_02 to describe the cabling interface between the USRA provided PI rack and the mission control and communications system (MCCS),

b. MCCS_SI_03 to describe the cabling interface between the USRA provided PI rack and the telescope mounted science instrument.

c. TA_SI_01 to describe the actual cabling within the SOFIA cable load alleviator device.

d. The global electrical schematic detailing the grounding scheme between the telescope, science instrument, counter weight rack, and the PI instrument rack.

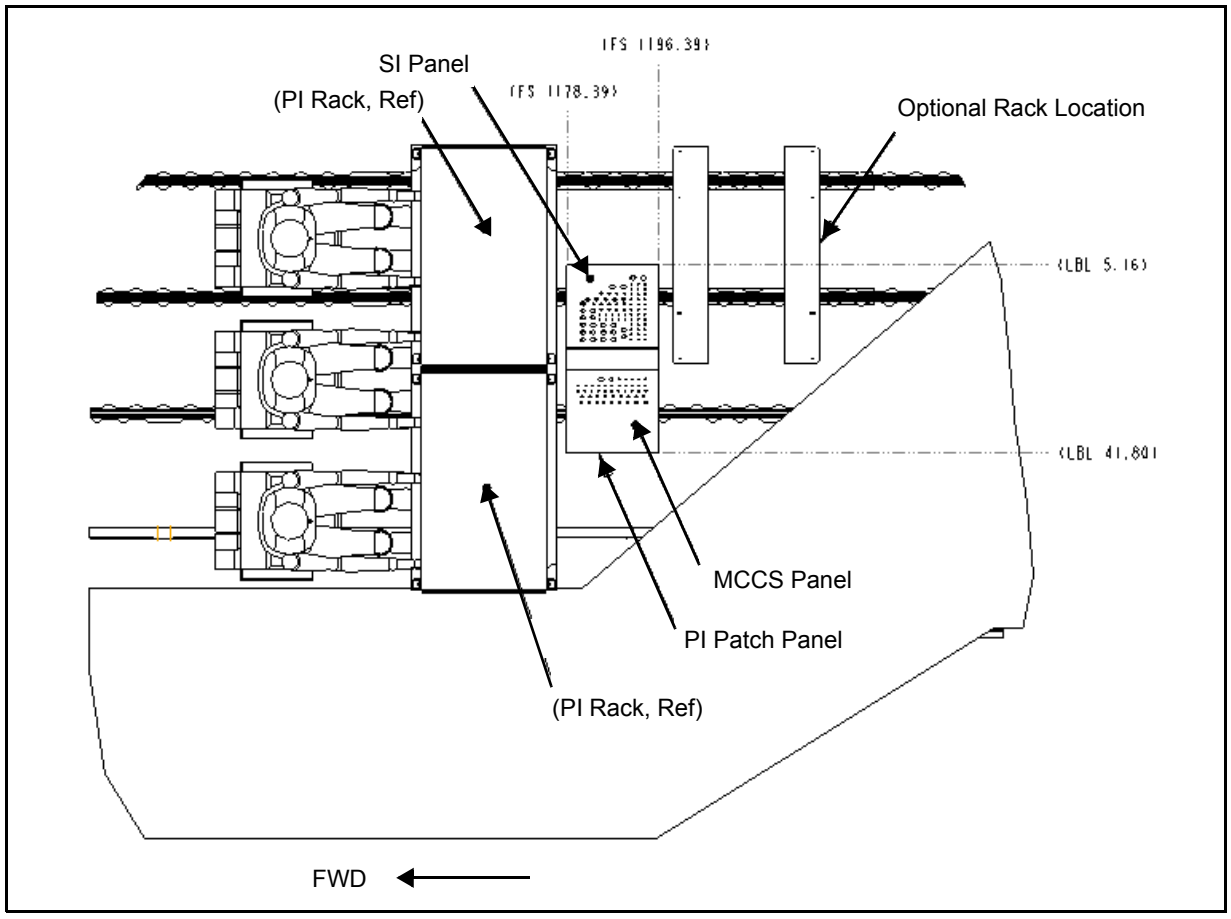


Figure 2-37. The Location Of The PI Patch Panel For Cabling Access To MCCS, Telescope, and Science Instrument Hardware

The PI patch panel (as illustrated) is divided into two sections – an MCCS panel (MCCS_SI_02) and an SI panel (MCCS_SI_03). The panel is located aft of the PI instrument racks. The layout of the MCCS panel is illustrated in Figure 2-40.

2.8.1 - The MCCS Patch Panel

Throughout the PI patch panel, the connectors are arranged to provide easy access to connect and disconnect cable assemblies. The connectors are group by type (e.g., power, data signal, video, etc.) and are labeled with a connector reference designator. Each connector on the patch panel has a spacing of at least one inch from any other connector. Connectors are identified by a reference designator (and SI connectivity reference number) for name or function, connector part number, and mating connector part number as part of the physical interface control document.

The MCCS interface position of the patch panel provides access to the MCCS and PI supplied rack power and ground lines, local area network (LAN) connections, audio, video, environment

sensors, and a global position system antenna. Electrical specifications for the various signal types are described, and connector pin-out table provided in the actual interface control document.

Instrument power is provided by an on board frequency converter and an uninterruptible power supply (UPS). Circuit breakers installed in the MCCS power distribution subsystem observatory power panel provide wire protection for the power feeds. FC power is shared between the PI equipment racks and the science instrument as budgeted by the SI team. FC power is subject to all outages experienced on the observatory. The UPS power is supplied from the MCCS PDS UPS located in the forward cargo compartment. UPS power will continue to supply steady state AC over to sensitive loads in the event of a power failure. UPS is used for battery backup to the PI patch panel. UPS power is proved and shared between all PI and SI requirement racks as budgeted by the SI team. Both the UPS and non-UPS power have circuit breaker protection with a 20 ampere limiting breaker. All aircraft breakers provide observatory power wire protection and are not intended as circuit protection for science instrument equipment. A 28VDC line is provided for the Mission Audio Distribution Subsystem. The return path for the 28VDC line is ground at a ground stud beneath the panel in the floor. This connector also provides the pins for an emergency power shutdown discrete. This discrete is provide by the observatory for use by science instrument equipment in shutting down power output from any instrument provide UPS and its use is mandatory if any science instrument UPS is present.

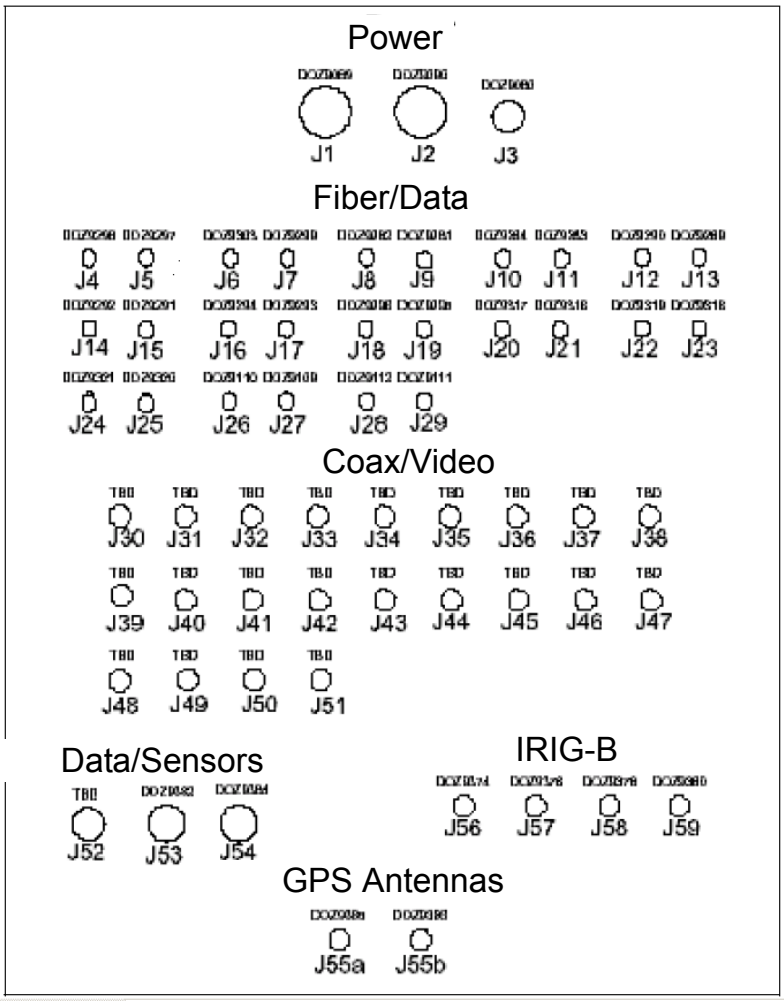


Figure 2-38. A View Looking Down On The MCCS Panel

The schematic above depicts the layout of the patch panel connectors for the MCCS interface.

The power and grounding approach for equipment in the PI racks and equipment connecting to the SI patch panel is depicted below. As an example, a portion of the FC power use is routed over the CLA drape for distribution at the science instrument patch panel. Power can be routed directly to the SI if no additional power is needed in the PI instrument rack. Grounding for science instrument equipment in the PI racks may be made to the rack structure. A pre-flight check verifies all electrical bonds established by the science instrument installation. Ground points are available on the PI patch panel via nut plates.

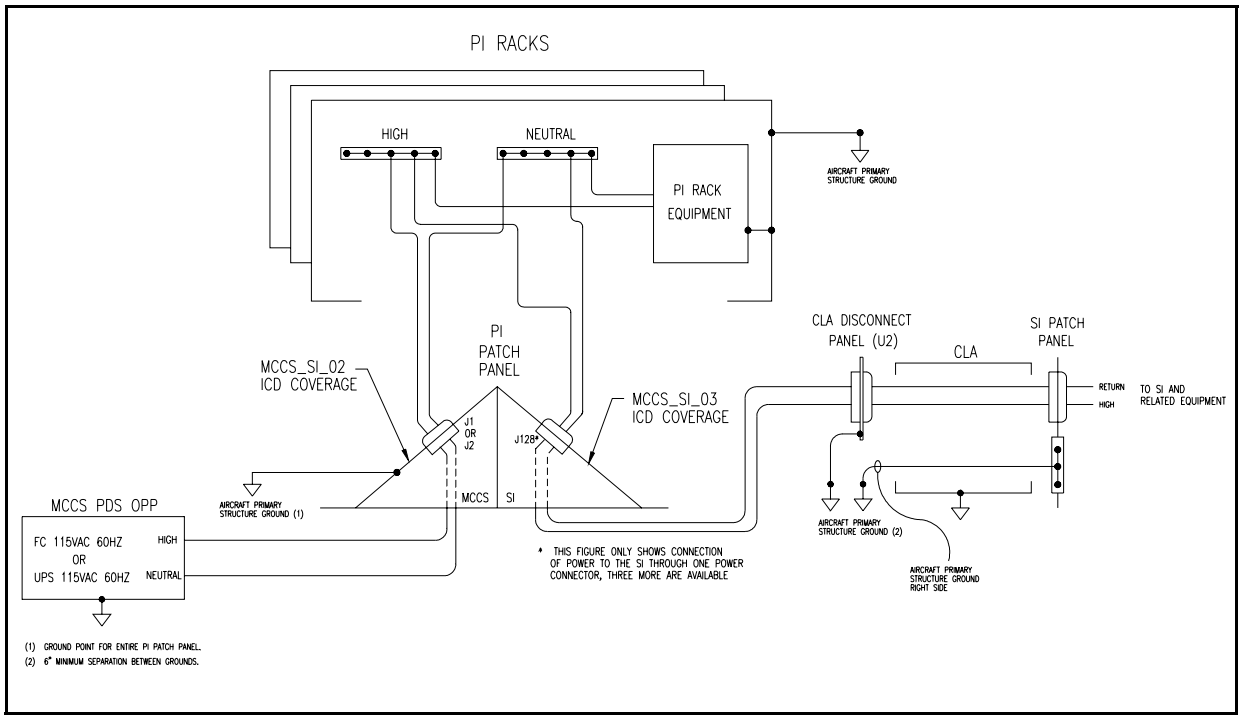


Figure 2-39. An Example Grounding Approach For Providing Instrument Power From the MCCS Patch Panel

Aboard SOFIA, fast Ethernet and a gigabit Ethernet LAN access is available for science instrument networking. The MCCS LAN is Ethernet based and support the 100BASE-FX and 1000BASE-SX standards. The available LAN connection points are used for science equipment in the PI racks or they can be patches over to the SI portion of the PI patch panel. Additional network connectors provide the interface for routed imager data from each of the fine field, wide field, and focal plane imagers. An additional fiber optic network connection is provided for the SOFIA mission audio distribution system. Specific USRA provided hardware is required to decode the digital audio stream needs for observatory headsets. For video signals, the observatory provides a serial digital interface (270 Megabit SDI) and separate RGB analog channels. Video channel routing lines require a USRA provided router controller head.

The MCCS patch panel also provides connectors for thermocouple lines, vacuum pressure sensor lines, and two GPS antenna connections. The GPS cables are signal feeds from the aircraft GPS antennas mounted in the window plus on both sides of the upper deck. Timing signals are provided. Please see the MCCS_SI_02 interface control document for detailed references to both GPS decoders and timing interface definitions.

2.8.2 - The Science Instrument Patch Panel

Opposite the MCCS patch panel is the SI cable drape panel that connects to a similar patch panel mounted on the port side of the telescope's counterweight flange. The layout of the SI patch panel is illustrated in Figure 2-40.

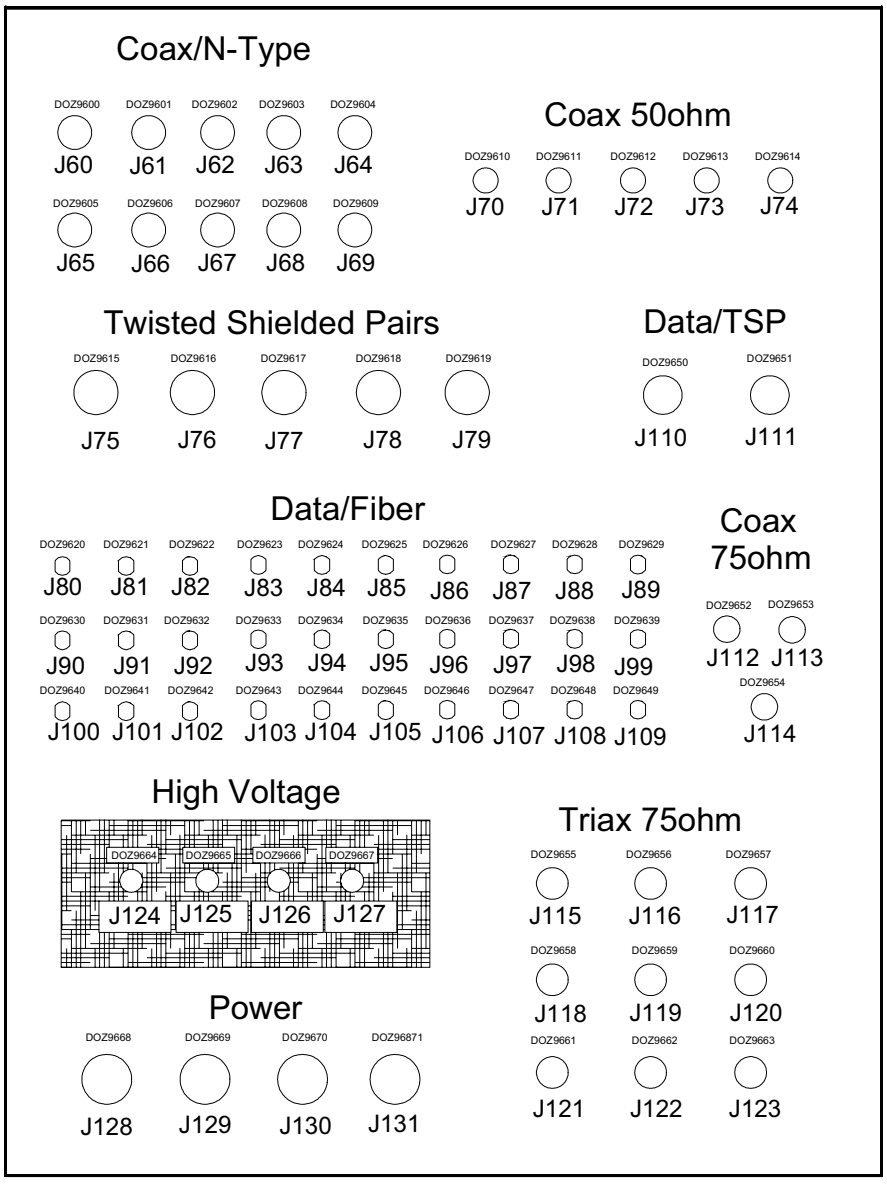


Figure 2-40. A View Looking Down On The SI Panel On The PI Patch Panel Aft Of The PI Instrument Rack

The SI portion of the PI patch panel provides a signal connectivity pool, communications, and power connections between the PI instrument rack/MCCS and the telescope mounted science

instrument. The SI patch panel consists of co-axial, tri-axial, twisted pair, and fiber optic lines. Additional lines are provides for high voltage signals and science instrument power connectors.

Communication lines at the SI patch panel are composed of twisted shielded pair lines, co-axial cables, and tri-axial cables. Shielding of the signal and communications twisted pair cables is provides on a per pair basis and pinned through designate contracts in the connector. Signal lines of the SI patch panel are composed of ten N-type connectors, five BNC adapters, and five connectors of twisted pair bundles, and thirty fiber optic ST style adapters. Four AC power connectors are available to route power to the science instrument. The observatory provides a discrete electrical connection for use by science instrument equipment in shutting down power from any SI provided UPS. In addition to the above connectors, there are four special purpose connectors/cables, suitable for DC high voltage lines. These lines are rated to a maximum of 15K VDC.

All of these connections are straight through, pin-to-pin connector to connector from the SI patch panel to the CLA disconnect panel to the telescope patch panel using the same science instrument connectivity reference numbers.

2.8.3 - The Cable Load Alleviator

The specific engineering details of cables used within the SOFIA cable load alleviator (CLA) are described in the interface control document TA_SI_01. This document describes the complete cables and lines arrangement of the cable load alleviator (CLA) and also the interface between the SI-cables and SI-lines and the TA cable load alleviator device. Furthermore, this document also defines the interface to CLA cabling to the SOFIA aircraft. The document defined the cable positions on the CLA running to the outer cable clamp on the cable tray (right side) and the aircraft intercostals (left side). The cable routing from this location to the disconnect panels are described in a separate physical interface control document. Details of the water-cooling hoses and instrument vacuum lines are also contained in TA_SI_01.

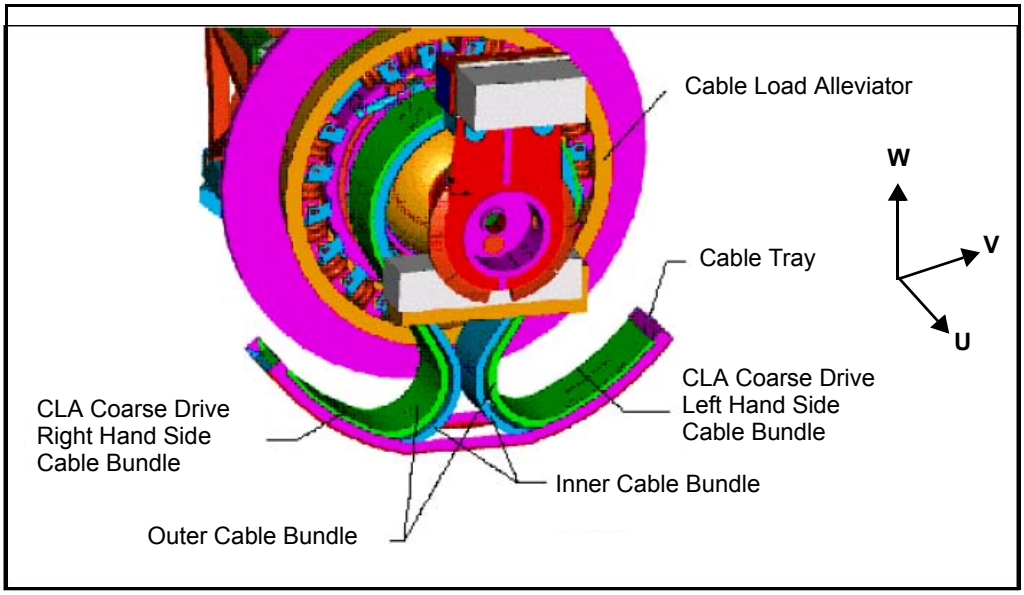


Figure 2-41. The SOFIA Telescope With An Illustration Of The Cable Load Alleviator (CLA) Configuration

All science instrument communication and signal cables are contained within the left-hand side of the CLA.

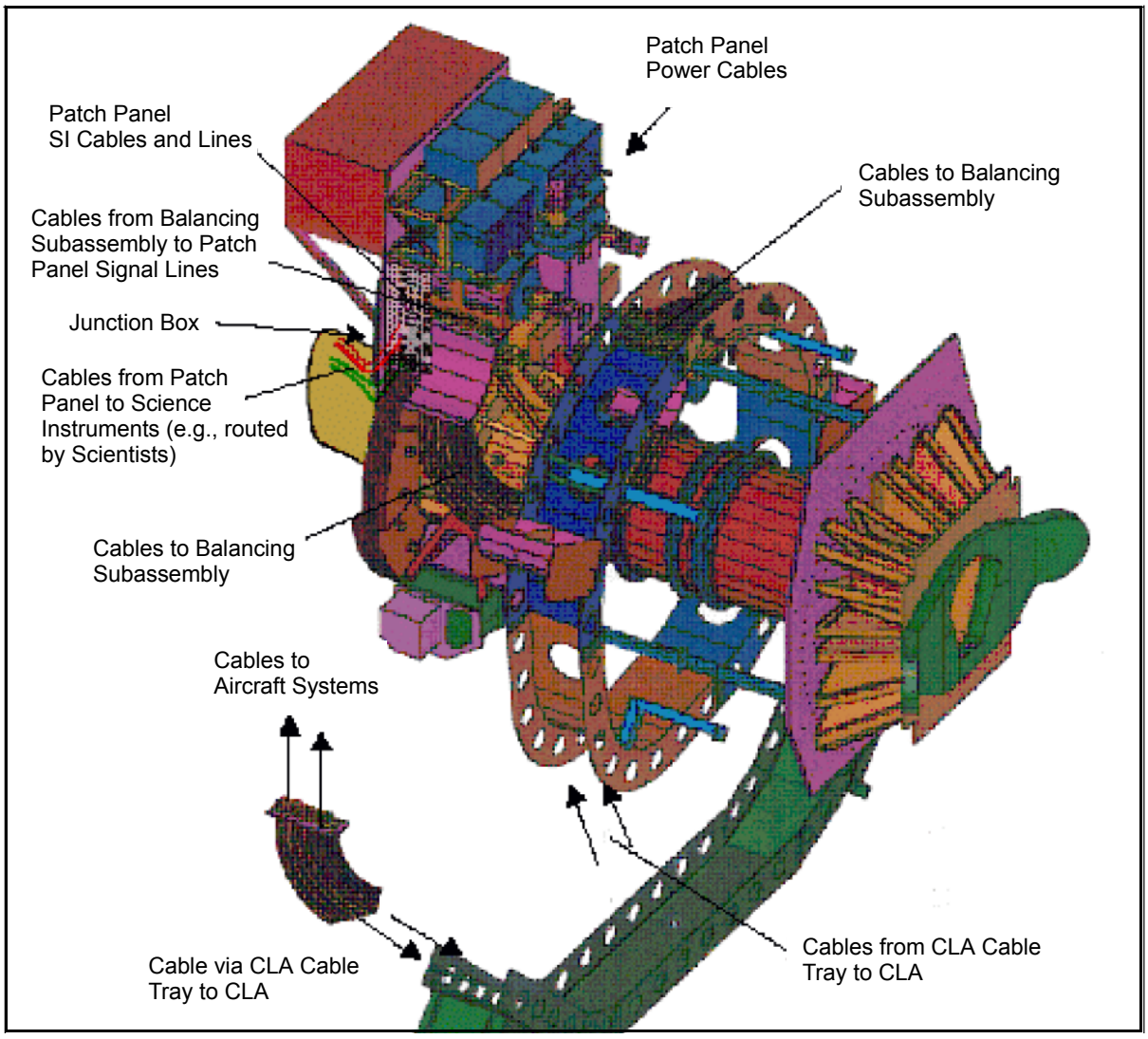


Figure 2-42. Cable Routing Aircraft System To Science Instrument With Signal Cables

2.8.4 - Science Instrument Grounding Recommendations

A separate interface document outlines the recommended grounding practices for science instruments and electronics mounted in the counter weight rack and forward PI instrument rack.

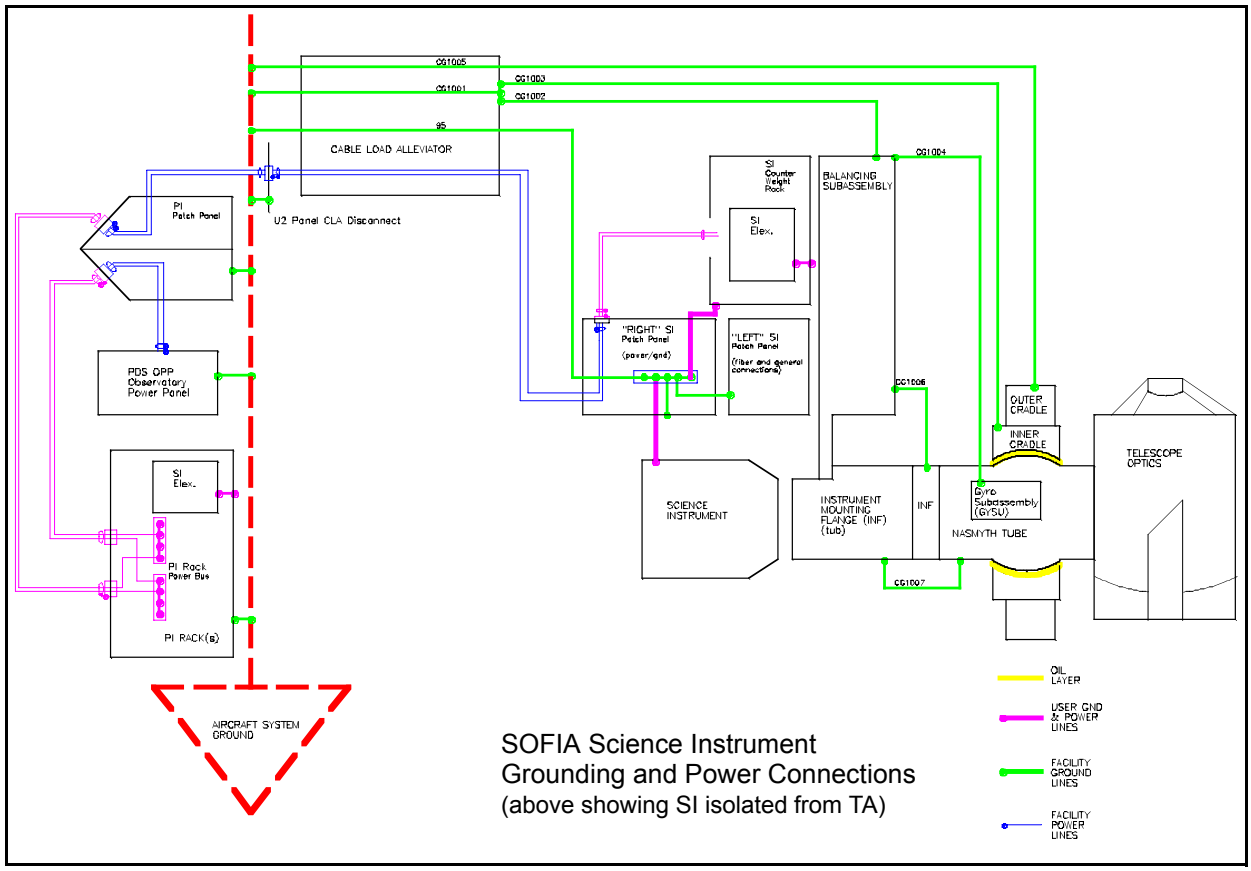


Figure 2-43. A Schematic Of Telescope, Instrument, And PI Rack Grounding

The science instrument is electrically isolated from the telescope structure.

2.9 - Science Instrument and TA Flange Pumping System

Among the lines within the SOFIA telescope cable load alleviator are three vacuum pump lines. The actual vacuum pumps are located in the aft portion of the aircraft's upper deck. Vacuum pump lines (76.2 mm/ 3 inches) outer diameter) run along the ceiling and drop near the CLA U4 disconnect panel. The lines from the pumps to the disconnect manifold is approximately 20 meters (66 feet) in length.

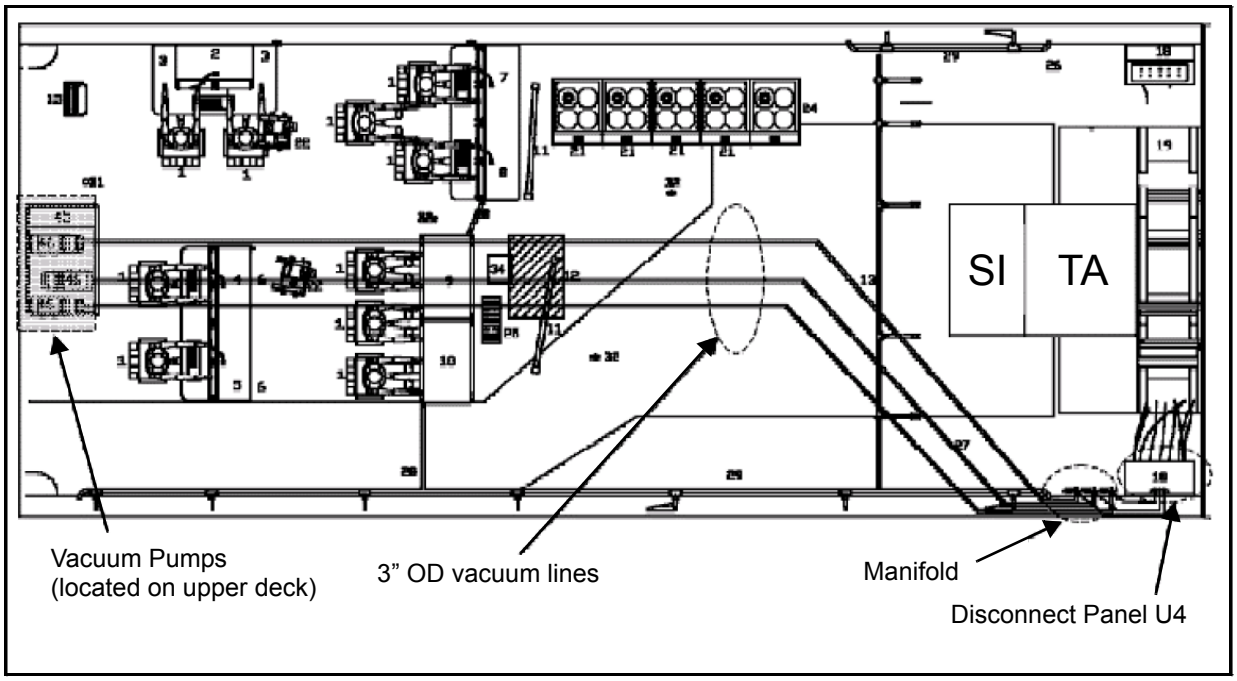


Figure 2-44. A View Showing The Science Instrument Vacuum Lines, Manifold, CLA, And The U4 Disconnect Panel

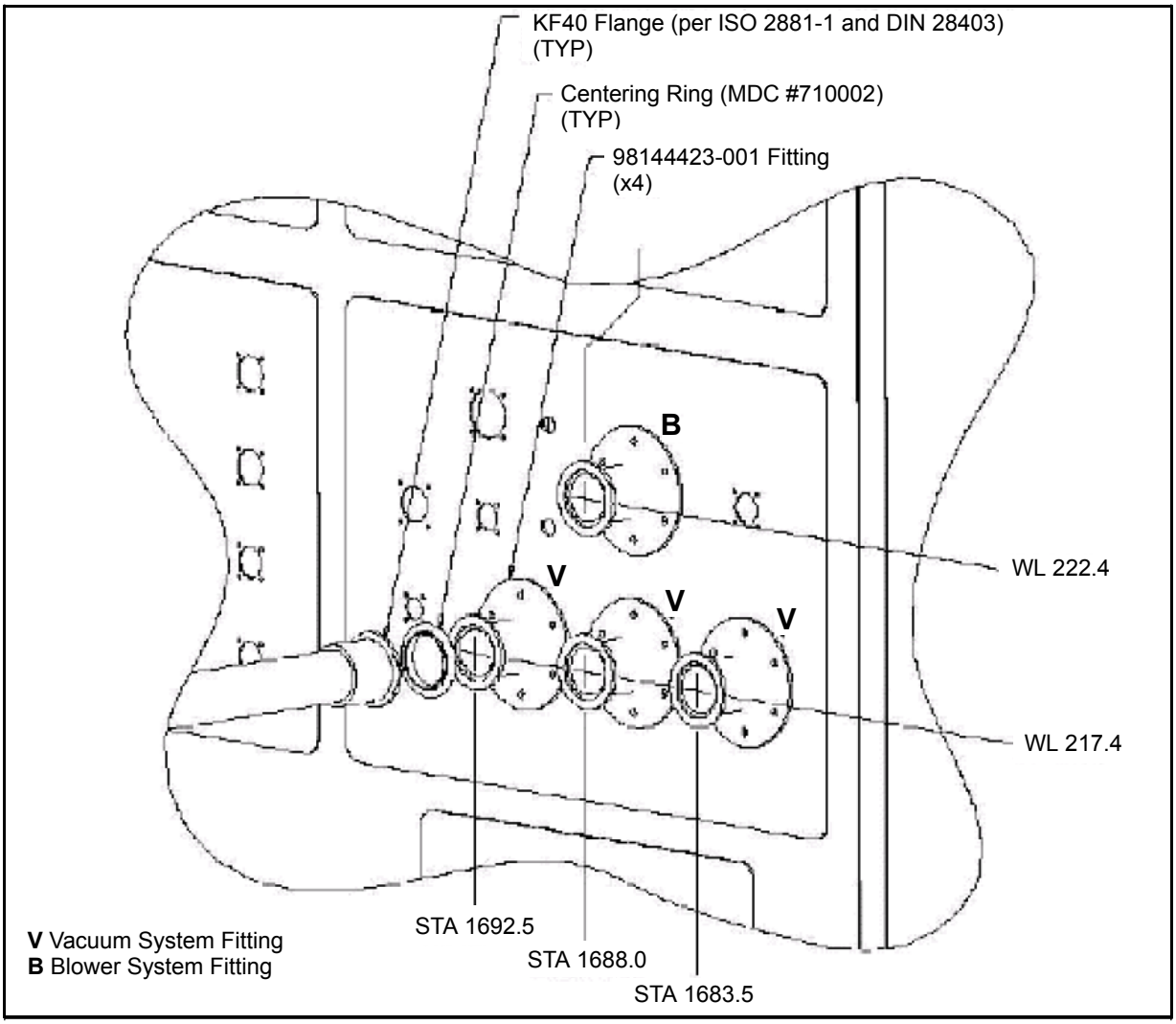


Figure 2-45. A Schematic Of The U4 Disconnect Panel With Fittings For The Three Upper Deck Vacuum Pumps

The details of this interface are described in the document titled the "Vacuum Pump System to Science Instrument". From the rigid aircraft vacuum lines, the lines drop in diameter 38.1 mm (1.5 inches) ID to run approximately 15 meters (49.21 feet) through the CLA to KF flanges mounted on the counter weight panel of the telescope assembly. Vacuum lines from the counter weight plate (CWP) to the science instrument or instrument mounting flange will also be 38.1 mm (1.5 inches) ID and will be provided by USRA. Flexible pumping lines will be available in a variety of lengths and will always end with a KF vacuum flange.

For instrument teams using the SOFIA SI vacuum pump system, USRA will provide suitable pressure sensors and electronics. Both the pressure sensor (ConvecTorr Gauge) and electronics (Varian Multi-Gauge) are described in the SI Vacuum System ICD along with the required operational cabling. The remote pressure sensor electronics is expected to mount in the PI instrument rack for science teams in need of pressure sensing.

The pumping speed at the SI flange is expected to be about 460 liters per minute at 1 Torr. This is based on a 20 meters (66 feet) of 72.9 mm (2.87 inches) ID pipe from the upper deck pumping station to the disconnect manifold and 15 meters (49.21 feet) of 38.1 mm (1.5 inches) ID hose from the disconnect panel to the science instrument flange on the telescope subassembly. This calculation does not include several plumbing unknowns such as bends, angles, orifices, or other restrictions.

Science instrument teams should expect that one vacuum pump would be used to evacuate the INF tub, and that two others will be for pumping on science instrument cryostats. However, instrument teams should expect only one pump operational immediately following SOFIA's operational readiness review. This one pump will have to serve both of the purposes listed above.

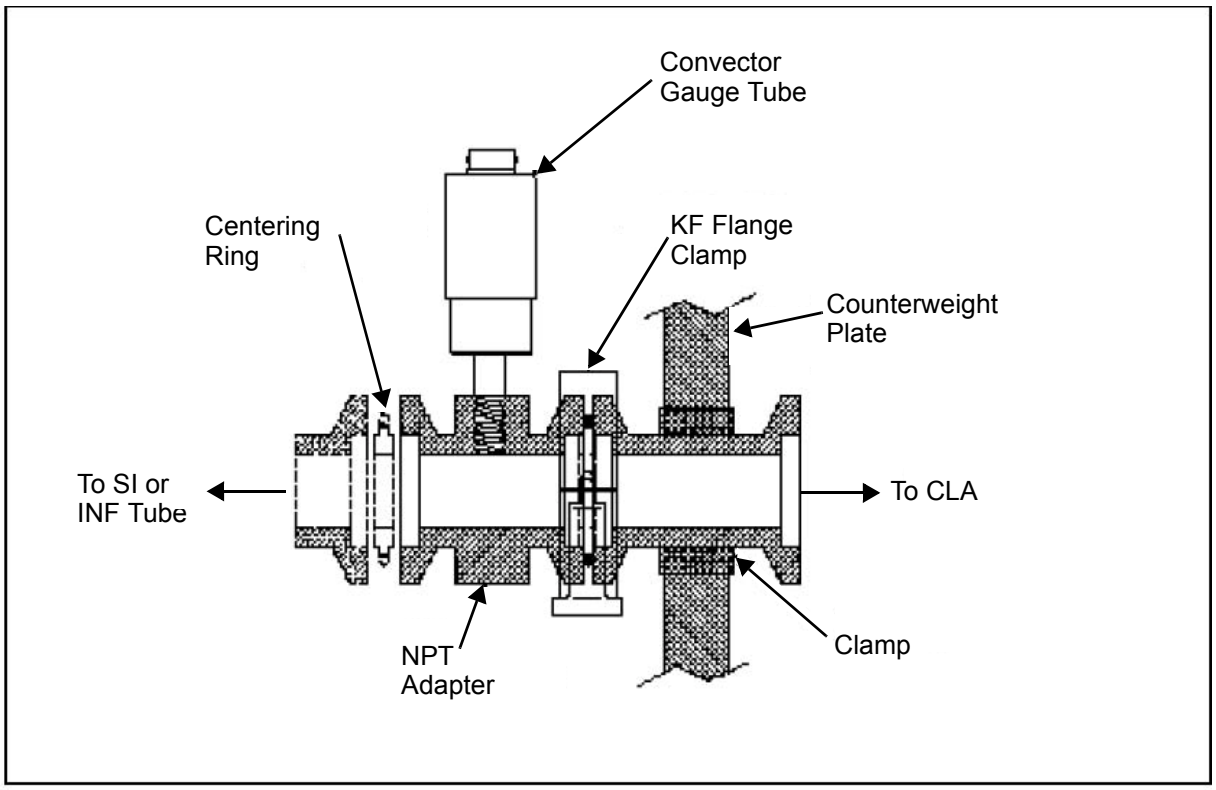


Figure 2-46. Schematic for Monitoring the Pump Line Pressure Attached to a Science Instrument

2.10 - Secondary-mirror Control

The articulated secondary-mirror control for the SOFIA telescope has both software and a hardware interface. The software interface, as described below, allows the science instrument team to set the amplitude, frequency, the phase delay of a trigger reference signal internal to the tilt-controller mechanism unit (TCMU). Changes in the telescope focus are also accomplished via software control of the focus-controller mechanism unit (FCMU). The telescope's TCMU also has a hardware interface as diagrammed below for direct control of oscillatory and programmed secondary-mirror motions.

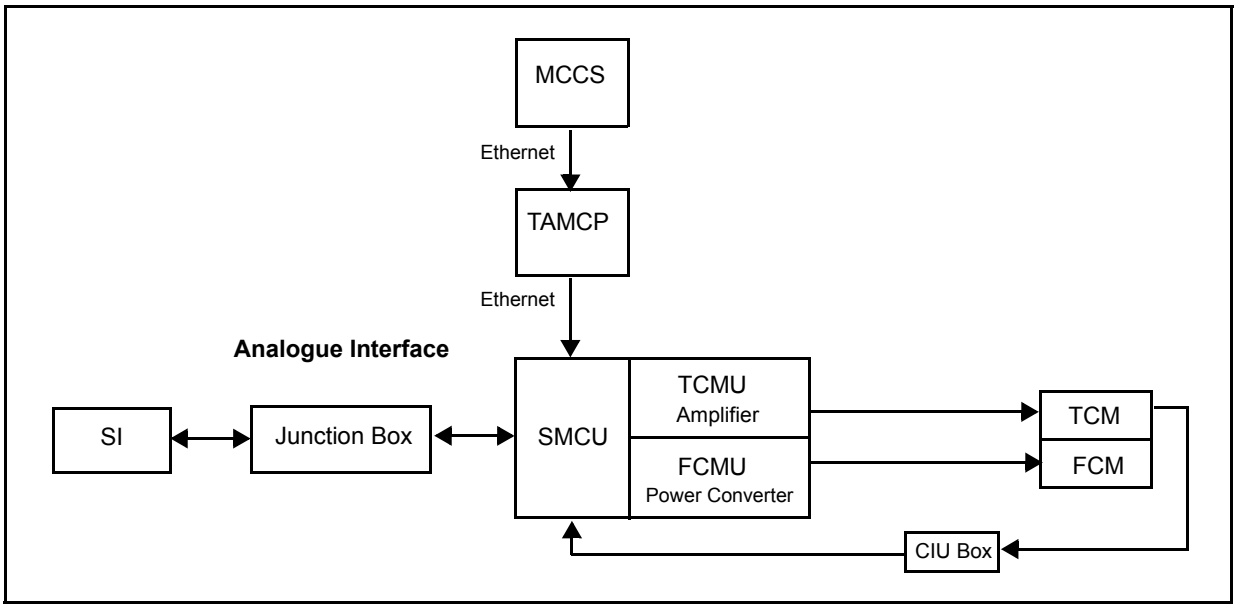


Figure 2-47. A Schematic Of Software And Hardware Connections To The Secondary-mirror Control Unit (SMCU)

The motions of the SOFIA secondary mirror are controlled along two-axes that lie in a plane perpendicular to the optical axis of the SOFIA telescope. The two-axes of secondary mirror rotation are called the R- and S- axes. Many of the details regarding the secondary mirror interface and all of the listed reference documents are located in TA_SI_04. As depicted, the science instrument connects to a junction box that is mounted on the front surface of the counter weight plate of the telescope. The junction box houses a number of tri-axial (low-noise) connectors for control of the TCMU. The lines are divided into several functionalities: analog inputs, analog output, TTL inputs, and TTL outputs. The analog outputs consist of signals with and without superposition of flexible body compensation.

The highest priority functionality of the secondary-mirror control is the direct analog control of secondary mirror motions. The R- and S- axis analog command lines allow the instrument team

to control-secondary mirror motions over a +/- 9-volt range with a scaling of approximately 125 arc-seconds/volt. Note that the system is design only requires the actual secondary mirror angle to be within the larger of 2 arc-seconds or 10% of the angle defined by the above scaling law for a given input voltage.

The R- and S- analog waveform output lines represent the actual measured angle about the respective secondary mirror axes. Users should note that the analog signals are transformed from a suite of 3 sensor signals assigned to the 3 chopper actuators and located in the tilt-control mechanism (TCM) between the secondary mirror and the chopper base (in a 120 degree configuration about the LOS axis). The signal represents the actual angle measure between the chopper base and the secondary mirror in the local secondary mirror coordinates. Note that commanded offsets to the secondary mirror position (by either the observatory or the instrument team) are not included in the analog waveform output lines. To meet the level-1 requirements of the NASA SOFIA program, servo-controlled motions of tilt-control mechanism are generated by the observatory's flexible body compensation (FBC). With a 'supposedly' perfectly steady telescope image (no chopping), the secondary mirror may in fact exhibit motions relative to the telescope structure. Such motions are manifest on the 'raw' analog waveforms lines but are subtracted from the analog lines noted as without FBC. The later lines should represent the motions of the secondary mirror in addition to those motions required by FBC image stabilization of the SOFIA telescope. The FBC signals are not applied at the R- and S- analog command lines available to science instrument teams. FBC control is added somewhere else within the TCMU electronics. Sensing of the secondary mirror position as a result of SI controlled motions on the R- and S- analog control lines should be determined through sensing of the R- and S- axis analog waveform outputs without FBC. Most instrument teams are likely to have only a passing interest in the FBC signal assuming a properly functioning system.

In addition to the analog control and sense lines of the secondary mirror control electronics are two TTL lines – one for synchronization of two- and three- point chopper and another designed as a TTL reference line. The configured for external control and operation, the TTL input line (the external TTL square wave chopper synchronization signal – Chop-Sync-In) is responsible for in-phase motions of the secondary mirror. Note that each transition of the TTL line is expected to initiate a transition of the secondary-mirror motions as depicted in Figure 2-48.

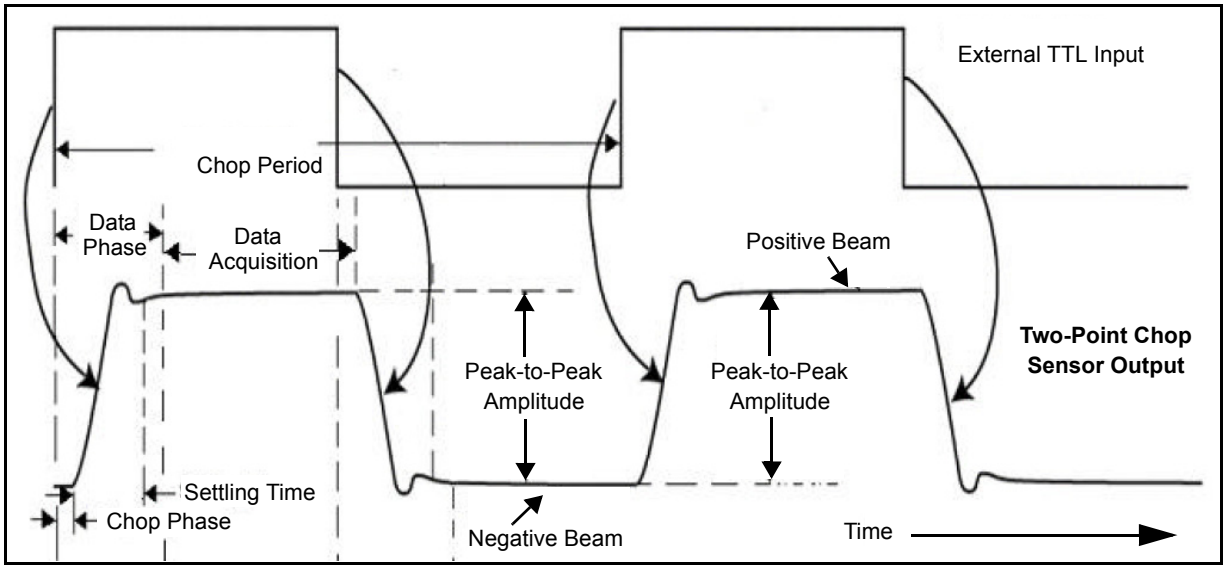


Figure 2-48. Definitions for External Command of Secondary-mirror Motions

The illustration shows external command of secondary mirror motions using the two-states of the TTL synchronization line.

As depicted, each rise and fall of the applied reference signal is needed to generate the complete 'square-wave' transition of secondary mirror motions. A novel feature of the secondary mirror control electronics is to use the same two-state nature of the TTL synchronization line to generate a three-point chopping pattern. Three-point control of the secondary mirror motions is illustrated in Figure 2-49.

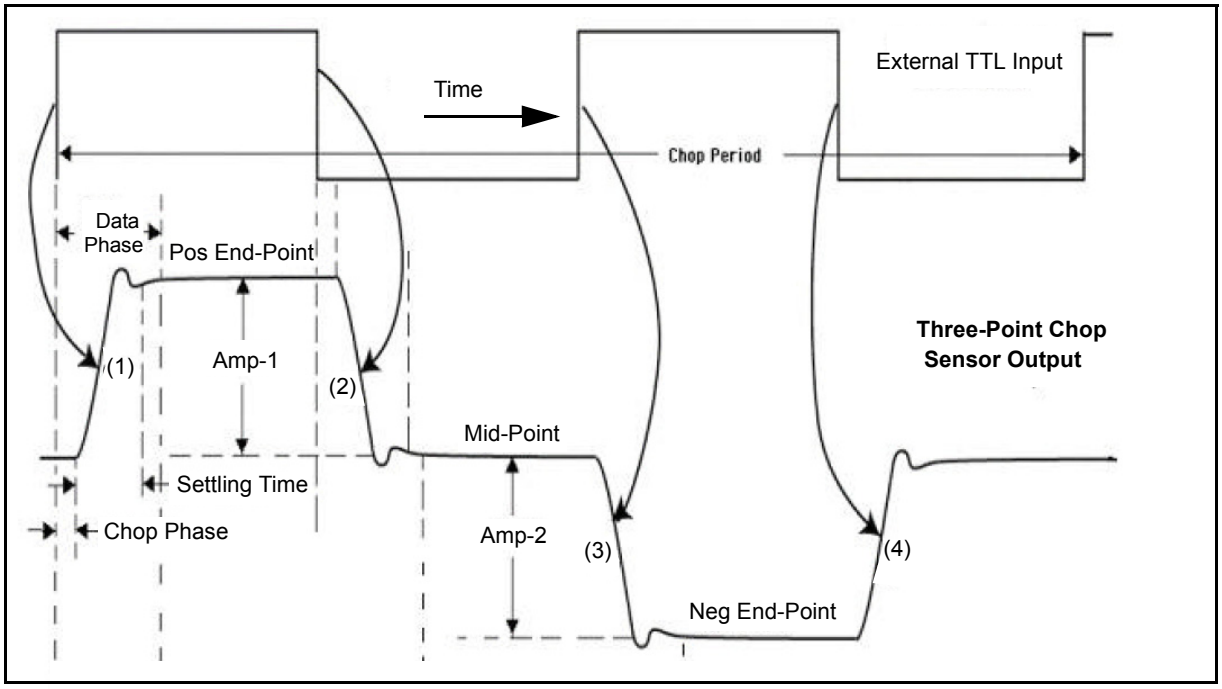


Figure 2-49. Three-Point Chopping Using A Two-State Synchronization Line With The Potential For A 180 Phase Reversal

As noted in the interface control document TA_SI_04, the figure above "shows that the TTL signal has a 180 degree phase ambiguity for the 3-point chop. The analog output described [previously] can be used [must] to monitor this phase degeneracy."

Without any analog and TTL inputs, it is possible to operate the secondary mirror controller and verify a stated level of functionality. In additions to the analog outputs mentioned previous, a single TTL output is available as a TTL trigger. This reference is subject to a software commanded 'phase delay' controlled by a designated keyword to the TCMU hardware. When zeroed, the TTL output should track any internal (or externally applied) reference signal. Adjustments to the chopper phase reference can serve as a means of 'phase-locking' instrument electronics to triggered secondary mirror motions. The phase delay is typically required for account for electrical and mechanical delays is system level secondary mirror motions. Using only internal software control, the observatory can verify secondary mirror motions by monitoring the analog and TTL outputs under a range of chopper amplitudes and frequencies. An external TTL generator can serve to verify the phase stability of the system. When monitored by the observatory, such diagnostics can provide a continuous baseline for successful secondary mirror chopping operations.

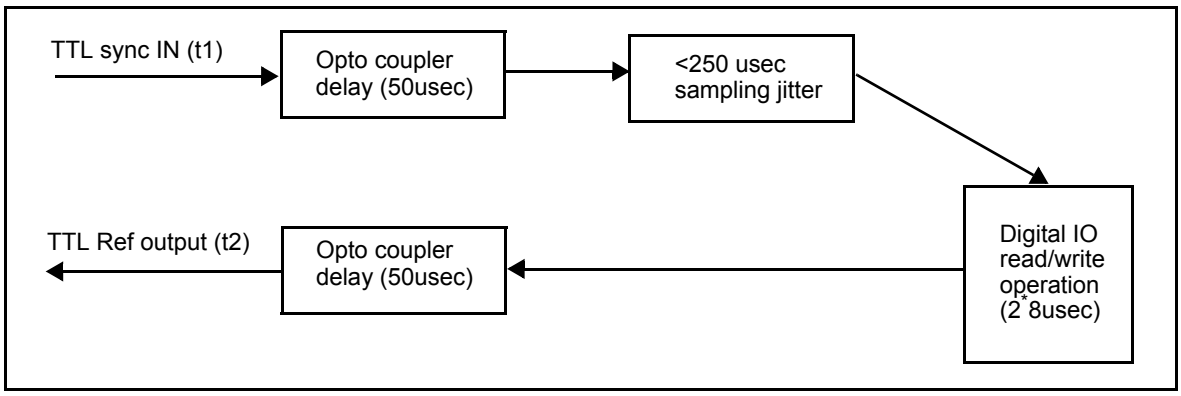

TTL sync IN (t1)
Opto coupler delay (50usec)
<250 usec sampling jitter
Digital IO read/write operation (2*8usec)
TTL Ref output (t2)
Opto coupler delay (50usec)

Figure 2-50. Possible Line Delays Schematic

Possible line delays associated with the built-in optical isolators associated with the secondary mirror TTL control electronics.

Instrument teams should note the tradeoffs between chopper amplitude (throw) and chopper offset. Whereas chopper amplitude refers to the A.C. signal of secondary mirror motions, the chopper offset is the corresponding D.C. component. The range of chopper amplitudes and offsets are defined in SOF-1011 as follows:

a. Amplitudes of up to 10 arc-minutes peak-to-peak in object space.

b. Offsets up to 5 arc-minutes in object space with an amplitude reduced accordingly.

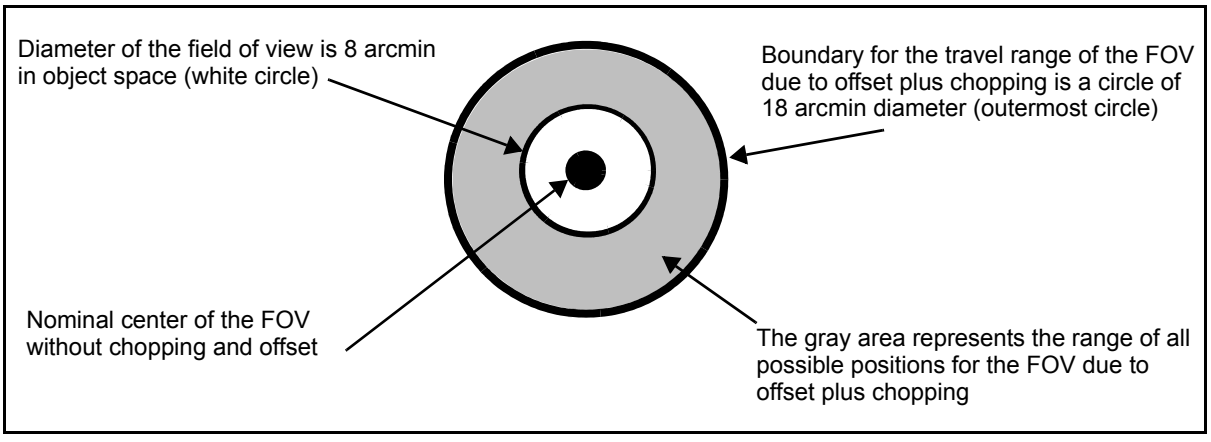

Diameter of the field of view is 8 arcmin in object space (white circle)
Boundary for the travel range of the FOV due to offset plus chopping is a circle of 18 arcmin diameter (outermost circle)
Nominal center of the FOV without chopping and offset
The gray area represents the range of all possible positions for the FOV due to offset plus chopping

Figure 2-51. Range of Secondary-mirror Field-of-View for Offset Plus Chopping Amplitudes

The mirror angle to object space angle conversion factor for the SOFIA F/20 system is approximately 3.74:1.

2.11 - SOFIA Software Interface

The Mission Controls Subsystem (MCS) is the major portion of the MCCS operation. It provides most operator supervisory control and monitoring of the observatory, especially of the telescope assembly. The MCS will provide the majority of the intersystem communications and facility control and monitoring via a local area network (LAN). The MCS will also provide other ancillary functions, including storage and retrieval of data, printing and plotting functions, computations, and intersystem data file transfers. The MCS equipment includes servers, mission support computers, and operator consoles.

The MCS consists of a suite of UNIX computers workstations, and possibly VxWorks embedded systems. Each console accesses a UNIX workstations. Through the UNIX operating system, users access network peripherals such as disk and tape drives, printers, and modems. The operating system allows a system administrator to assign privileges to those resources. The servers and workstations will execute software applications and provide access to high-capacity disk and tape storage drives. Any observatory workstation will be able to print to any of the printers located in easily accessible areas of the cabin. This approach allows for reconfigurable workstations and provides reliability through redundancy.

The MCS housekeeping will archive and make available by name all data received from all subsystems. Housekeeping functions, accessible via the MCS SOFIA Command Language (SCL) will return the most current information for all facility data requests without data loss. All data will be accurately time-tagged upon receipt by the MCS. Where possible, data will be time-tagged when it is generated. Time synchronization will be provide through the observatory with an IRIG-B timing distribution system accurate to at least 1 ms. MCS workstations will be synchronized to less than a millisecond via custom software using the MCS LAN.

The MCCS LAN used for MCS communications is a redundant fault-tolerant network. The MCCS LAN minimizes the network latency to ensure adequate transfer of dynamic, time critical data. The LAN transports this data among aircraft, telescope, and science instrument systems to facility data processing functions. In addition, a dedicated Ethernet network (100 Base T or Gigabit) will be available to the science instruments. At least 32 IP addresses, available via numerous physical ports at the MCCS consoles, will be made available to the science users. The LAN will also provide Internet access via ground umbilical cable connections to the N211 hangar and support facilities at the USRA SSMOC.

2.11.1 - MCS Command and Keyword References

The documents referenced below constitute a complete library of all the SCL commands and keywords. All of this information is maintained within the SOFIA development environment (that is, in the XML files used to control SOFIA behavior), and so it should accurately represent the current system's configuration.

The documents include implemented components, as well as components planned for future releases. As the key below describes, the status of each component is presented in the reference tables with the information for that component.

2.12 - SOFIA Science Instrument Commissioning

All of the SOFIA science instrument interfaces are verified prior to the pre-flight review. A subset of the interface control documents (ICDs) is verified prior to the pre-ship review. The following sub-sections list how and when each of the science instrument related ICDs are verified by design. Final proof of ICD compliance by successful operation is the subject of the section following this one.

2.12.1 - Global ICDs

Layout of personal accommodations: *Each instrument needs to specify the overall layout of the instrument in the observatory. This should include the science instrument racks required (both the PI rack and TA rack), the number of consoles required and the expected locations of science instrument team members during take-off/landing and during standard mission operations. This layout needs approval prior to the pre-ship review.*

SOFIA coordinate system: *Each instrument needs to specify the location of the SI image plane with respect to the science instrument flange. This information is needed for adequate control of the telescope in the SI coordinate system. An update of this information is provided via measurements from the TAAS and after the first few flights.*

Science instrument envelope: *Each instrument needs to supply three drawings that show how the instrument can fit within the science instrument installation envelope, the science instrument service envelope, and science instrument dynamic envelope. Each of these drawings can represent the science instrument with approximate dimensions so long as the approximate science instrument volume falls within the maximum instrument volume required of SOFIA. Clearly, installation tests aboard SOFIA serve as the final verification of compliance with the SOFIA science instrument envelopes. The science instrument mass and center of gravity are needed prior to the pre-ship review.*

Science instrument grounding scheme: *Each instrument needs to supply an appropriate grounding schematic for the instrument. This need only show how science instrument grounding is managed and how the instrument's grounding approach is consistent with the observatory's science instrument grounding requirements. Major grounds for the instrument are outlined with their connection to the aircraft grounding points. Isolation of major science instrument components from the aircraft structure also needs to be specified. This needs approval prior to the pre-*

ship review.

2.12.2 - Telescope ICDs

TA_SI_01: *Each instrument needs to provide a list of the science instrument cables and their connector interface to the aircraft patch panel and from the corresponding telescope patch panel. The list should include the cable designation, function (control, sensor, power, et cetera), and connector specification. All power lines should be called out.*

TA_SI_02: *Verification of the science instrument flange requires the instrument team to provide a drawing package for comparison with that of the observatory. This should include the dowel pins and bolt patterns of the as built instrument flange and the anticipated science instrument mass and center of gravity. Sign-off of a science instrument flange drawing for conformance with the telescope flange by the USRA engineering staff is needed for successful completion of the pre-ship review. All areas of the telescope interface are completely verified only during science instrument installation on the telescope. All instrument weights and c.g.'s are verified following installation on the telescope. All applicable documents should be updated for as-built consistency for a completion of the science instrument post-flight review.*

TA_SI_04: *Each instrument needs to provide a diagrammatic schematic of connections to the telescope tilt mirror controller (TMC). The schematic should also include a list of the cables and connector specifications to be provided by the SI team in controlling the TMC. Note that the TMC interface requires power for SI-provided pull-up resistors for the optically isolated open collector TTL outputs provided by the TMC chassis. A second table is needed to list 1) whether the TMC is driven internally or externally, 2) the range of frequencies used when driving the TMC externally, 3) sample waveforms when driving either the TTL or analog inputs, and 4) whether the internal phase reference is also used and the range of phase offsets expected. All schematics and tables are needed for the pre-ship review and should be updated for completion of the post-flight review.*

TA_SI_05: *Instruments requiring the telescope counter-balance weight science instrument rack need to note when they desire to install their equipment in the limited number of racks available. All SOFIA provided racks are available when the instrument arrives in the SSMOC. Assembly of science instrument equipment in the SOFIA racks should be completed prior to the pre-install instrument review. A schematic and table is required that list the equipment, equipment dimensions, the equipment weight, the locations within the rack when assembled for installation on the TA, and any cabling between the counter balance rack and the science instrument. This material is needed for review prior to the pre-ship review. All rack weights are verified prior to the pre-install instrument review.*

2.12.3 - MCCS ICDs

MCCS_SI_01: *Instrument teams requiring an approved, modified KAO PI instrument rack need to note when they desire this rack for installation of their equipment. A suitable rack will be shipped to the instrument team's home institution when it is needed. A schematic and table is required that lists the equipment, equipment dimensions, the equipment weight, and the equipment locations within the rack when assembled for installation aboard the aircraft. Note that mounting diagrams should include the location of the audio distribution patch panel that is provided for science instrument team use by the observatory. Any needed power patch panels supplied by the observatory should also be included. This material is needed for review prior to the pre-ship review. All rack weights are verified prior to the pre-install instrument review.*

MCCS_SI_02: *Instrument teams need to provide a table of the cables and connectors used for this interface that includes power, networking, audio, video, and GPS signals. The table should include function and connector specification. A separate table should show the division of power between the frequency converters and the uninterruptible power supply (UPS) sources. The instrument team should indicate how grounding is accomplished using the ground point provided. A review of this material is required prior to the pre-ship review. Any changes are noted prior to the post-flight review.*

MCCS_SI_03: *Instrument teams need to provide a table of the cables and connectors used to connect to this patch panel located just aft of the PI instrument rack. The MCCS_SI_03 patch panel contains all of the cable connectors running through the telescope cable load alleviator. This includes power cables, twisted pair, co-axial cables, tri-axial cables, fiber optic cables, and high voltage cables. Only those cables needed for science instrument operations should be listed. All cables should include their mating connector specification. Power lines should also include the grounding approach and a list of the expected power requirements for each power cable. This information is required prior to the pre-ship review*

MCCS_SI_04: *Verification of the software functional observatory interface is needed at two levels. For the pre-ship review, the instrument team should demonstrate a successful exchange of rudimentary commands with the observatory. Prior to the pre-flight review, the instrument team should demonstrate the use of all anticipated commands for successful science instrument control of the observatory. The list of tests to be performed prior to the pre-flight review and the MCS commands to be executed should be completed prior to the pre-ship review of the instrument. Expected operating modes of the telescope (chopping, nodding, scanning, et cetera) for successful science instrument operations should also be reviewed prior to the pre-ship review.*

2.12.4 - Aircraft ICDs

SI_AS_01: *If the instrument team is using an instrument rack other than one provided by the observatory, then they are required to provide the appropriate design drawing for conformance*

with the observatory ICD. This interface should closely resemble that of the approved, modified KAO PI rack – MCCS_SI_01. ICD conformance is required for the pre-ship review.

SIC_SI_01: *If the instrument team intends to use the observatory provide science instrument cart, documentation is required to demonstrate how the instrument will mount on the cart provided. The instrument teams should also indicate when this cart is required prior to the pre-install instrument review. The needs of the instrument team should be stated prior to the pre-ship review.*

SIC_AS_01: *Instrument teams employing their own carts for installation aboard SOFIA need to demonstrate adherence to the floor loading requirements of the observatory and compliance with the observatory's installation envelope restrictions. ICD conformance is required before the pre-ship review.*

SIC_SSMO_01: *Successful compliance with SIC_AS_01 and the Global 09 should satisfy this ICD.*

Vacuum Pumps: *Instrument teams should diagram their required pumping configurations for pre-flight, flight, and post-flight operations. Monitoring of pressure sensors are the responsibility of the instrument teams and not those of the observatory housekeeping system. This is required prior to the pre-install review for the instrument.*

2.12.5 - N211 ICDs

SSMO_SI_01: *Instrument teams need to provide a list of needed equipment prior to the pre-ship review. Although very little equipment is expected to be available immediately after ORR, the list includes laboratory space, a few tables and cabinets, network connections, and a PC configured for e-mail, web browsing, printing, and standard office applications. Any specialized equipment should accompany the science instrument. This list is required prior to the pre-ship review.*

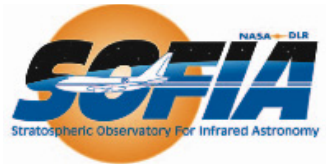
SSMO_SI_02: *The instrument teams should list any observatory test equipment expected for simulation of point sources or instrumental beam mapping. Very little equipment is currently available although special request can be considered. This list is also required prior to the pre-ship review.*

SSMO_SI_03: *The instrument team's requirements for cryogenic support during their stay at the SSMOC is require prior to the pre-ship review. This includes the quantities of cryogenic gases (LN2, Lhe), any transfer tubes or storage vessels or funnels, any room temperature gases (N2, He), any gas regulators or hoses, and any after hours staffing requirement or access needs. All these needs should be stated and clarified prior to the pre-ship review.*

2.12.6 - Operational ICD Verification

Each phase of the science instrument operations and their relationship to final ICD verification must be detailed. This is to include: laboratory operations, aircraft installation, aircraft ground

operations, aircraft in-flight operations, and also post-flight instrument operations. Verification of each instrument ICD is to be listed in a table with a ‘check’ column for a designated official to initial. A sample ICD verification document is provided in the appendix to this manual.



CHAPTER 3

Airworthiness

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3.1 - Science Instrument Certification

3.1.1 - Introduction

The primary purpose of FAA science instrument certification aboard SOFIA is SAFETY. The guidelines in this manual follow those of the Federal Aviation Administration (FAA) documents (FAR Part 25). The FAA is concerned with the safety of personnel associated with flight, and all aspects of the aircraft will be certified under FAA guidelines.

Certification is not difficult, but it does require following specific steps from conceptual designs through instrument construction, installation, operations, and maintenance for the purpose of maintaining a safe environment aboard the Observatory.

The purpose of this airworthiness and certification procedures manual is to lead a SOFIA science instrument builder through the certification process with information and examples on all aspects of an instrument design that are required to comply with FAR Part 25 guidelines for certification. These requirements include mechanical and electrical design and analysis, instrument construction, testing, hazard identification and analysis, operations, and instrument maintenance. This manual has been compiled through the efforts of the SOFIA FAA SI Airworthiness IPT, which includes scientists, engineers, FAA Designated Engineering Representatives (DERs), and science instrument builders. Some processes and details have not been fully defined at this time, but will be inserted as they are produced. Instructions will evolve and become more detailed as the first instruments proceed through the certification process.

This Introduction will define the roles and responsibilities of those involved in the certification process. Section 100.1 has a short general list of required steps, from conceptual design review to conformity and compliance inspections. Section 100.2 describes the sections of this manual and Section 100.3 discusses scheduling.

3.2 - Science Instrument Certification: Methods and Roles

Science instrument certification will involve communication between the science instrument (SI) team and the science instrument airworthiness Integrated Product Team (SIA-IPT) as mentioned above, the FAA Designated Engineering Representatives (DER), and the Designated Airworthiness Representatives (DAR). The Airworthiness IPT is responsible for the production of the material in this manual and also can be viewed as a resource for the SI builder on questions specific to instrument certification.

The Federal Aviation Administration is responsible for safety aboard all commercial and privately owned aircraft. The FAA appoints individuals to review designs, to make inspections, to review operations and maintenance, and to act on behalf of the FAA to review new designs and require-

ments for aircraft safety. The Aircraft Certification Office (ACO) supervises dERs, while the Manufacturing Inspections District Office (MIDO) supervises DARs. The Certification Maintenance Office (CMO) will monitor SOFIA Operations. The following sections discuss the roles and responsibilities that are held by each of these groups.

General information and the steps involved in FAA certification, from initiation of a certification project, through testing, conformity inspection, and award of a Supplemental Type Certificate (STC) are listed in Appendix III.

3.2.1 - Designated Engineering Representative (DER)

The DER is a representative of the Federal Aviation Administration (FAA) and is quite knowledgeable in aircraft certification and all aspects concerning safety of flight. The DER is appointed and supervised by the cognizant FAA Aircraft Certification Office (ACO) that handles all engineering issues with respect to certification. The DERs have specific areas of expertise regarding safety, such as structural, electrical, mechanical, hazardous materials, etc., and are responsible for presenting the science instrument designs, documents, analysis, testing, etc., to the FAA in order to acquire the Supplemental Type Certificate (STC) required for flight aboard the observatory. The DER will aid the science instrument builder in developing the proper documentation package that will then be presented to the FAA. The documentation package will include design specifics, mechanical designs, stress analysis, electronic designs, hazard analysis, maintenance plans, operations scenarios, and any other item required to show compliance of the SI design to the FARs. The science instrument documentation package (or data package) will also include test plans that are required in order to certify a particular aspect of the system or subsystem. The DER will begin the process of identifying aspects of your instrument during the conceptual design review.

For SOFIA, the compliance checklist is kept by the administrative DER for the entire project and individual teams do not need to be concerned with this list. As designs become more detailed based on design reviews, the identification of critical items checklist may involve several iterations with continual discussion between the science instrument builder, the Airworthiness IPT, and the DERs. Although the FAA has the right to witness any tests that are done, they can choose to designate a DER to witness a particular test.

DERs will assist the SI team in identifying the components of a system that will require testing.

3.2.2 - Designated Airworthiness Representative (DAR)

Another very important aspect in the certification process is the finding of ‘Conformity.’ Conformity is an inspection process in which it is determined whether or not the physical instrument conforms to (is the same as) the design data in terms of dimensions and materials. An FAA MIDO inspector conducts the conformity inspection or the inspection is delegated to a DAR. The DAR is appointed and supervised by the Manufacturing Inspection District Office (MIDO) and is respon-

sible for inspections of all parts, test set up, and other conformity issues. Once your design is complete and before you begin to build, drawings and a request for conformity are submitted to the FAA ACO by the DER. The ACO will then contact the MIDO and the request for conformity will be issued to the DAR, who is then responsible for conducting the conformity inspection. A conformity inspection of a part means that all dimensions, materials, process call outs, and tolerances are checked to make sure that they are exactly as have been specified on the drawing.

3.3 - Compliance vs. Conformity

The FARs are the rules that must be followed to obtain certification. Compliance with the rules is determined by the DERs working in conjunction with the engineers of the FAA ACO. Compliance is determined by reviewing the documentation provided by the SI team, by conducting any required tests, and by conducting a 'Compliance' inspection on the aircraft. 'Conformity,' however, is the determination by the DAR that the parts that are to be installed on the aircraft are the same in every particular as the design that is defined by the engineering data.

3.4 - Operations: Flight Standards District Office

Once your instrument has received its STC, and during SOFIA operations the FAA office that will be responsible for the training of personnel, continued Airworthiness, etc. is the Flight Standards District Office (FSDO). This office is charged with oversight of the maintenance of the aircraft and subsystems (including SIs) on board the aircraft. More information will be forthcoming on the topic of operations and continued Airworthiness.

3.5 - Science Instrument Certification: General Process/Overview

Certification of a science instrument will involve a conceptual design review and submission of instrument design data. The submittal data will include instrument engineering (build to) drawings, structural analysis that verifies the instrument design meets all aircraft load conditions, electrical load analysis, safety procedures, and system safety assessment for the complete instrument. Drawing standards and examples are available as are samples of approved data. The Science Instrument Airworthiness Manual contains detailed information about the required submittals.

The following list is intended as a very brief overview of the airworthiness requirements process, data deliverables and responsibilities. Further details can be found in the complete SOFIA SI Airworthiness Manual.

3.5.1 - Conceptual Design Review (CODR)

Conceptual design review is to give information on the overall system design and begin to identify critical safety issues. This is the first opportunity to show the DERs the mechanical and electrical specifications and to discuss instrument hazards. The outcome of this review should be a list of action items that need further details or analysis on both the SI package and the airworthiness process particulars. These may include discussion of particular instrument hazards such as cryogen use, calibration gases, and failure modes. General instrument design parameters will be discussed.

3.5.2 - SI Airworthiness Submittals and Control Process

1. SI Team assigns an internal team airworthiness liaison to L3/USRA.

The SI team liaison will communicate with L3 and USRA regarding all airworthiness submittals, questions and discussions and will be responsible to develop an understanding of the SI guidelines and practices as much as possible. The liaison is to maintain communication with the DER/L3/USRA as necessary to enable clarity in status and process for airworthiness.

For example:
HIPO - Ted Dunham
FORCAST - George Gull

2. SI Team submits data to Bill Johns.
3. Bill Johns forwards data on to appropriate DER.

- Schwartz for structural submittal data
- Todd Seach for Mechanical systems and safety submittal data (SSA, FHA, FMEA, FTA and test plans)
  Bill Johns reviews electrical submittal data

4. Appropriate DER reviews and responds to submittal through Bill Johns.
5. Comments directed to team from Bill Johns back to PI/Airworthiness liaison for team.
6. Iterate package as necessary.
7. Keep track of the submittal data and responses using the USRA provided spread-sheet. The spread sheet will be presented as part of the SITR meeting update.

For submittal status and to solicit comments call Bill Johns directly. If you have a specific question for any of the DERs then they can be contacted directly for assistance and clarification. Specific engineering and safety concerns/questions can be addressed to Ted Brown (USRA chief engineer) and Richard Bacher (SRM&QA manager).

Bill Johns 254-867-4148	Bill_Johns@ISL-3Com.com
Peter Schwartz 830-438-7486	peter_schwartz@jetaviation.com
Todd Seach 903-457-5749	todd_seach@hotmail.com>

Ted Brown 650-604-6020	tbrown@mail.arc.nasa.gov
Richard Bacher 650-604-3912	rbacher@mail.arc.nasa.gov

3.6 - Construction, Inspection, and Testing

This phase of the program will include part manufacturing, part conformity inspection, and testing.

During the part manufacturing phase, some or all parts will require part conformity by an FAA DAR. Additionally, conformity will be required at sub-assembly and final assembly phases. The scheduling of conformities must be closely coordinated with the Airworthiness IPT and the FAA DAR.

Part or assembly testing (such as proof & burst) will require 100% FAA conformity of the unit, FAA approval of the test plan, and 100% FAA conformity of the test setup prior to commencing testing. It also requires that the FAA (or delegated DER) witness the test.

3.7 - Obtaining Final Certification

Successful part or assembly testing are complete per FAA DER approval of the documented results. The science teams now must submit the final airworthiness deliverables (see section 150.6) for DER review and approval. This includes the Electromagnetic Interference (EMI) and Functional tests.

The EMI and Functional are ground and flight based tests to ensure there is no interference with the aircraft electrical system and the science instrument operates properly as per design. Similar to the part or assembly test, these tests will require 100% FAA conformity of the entire science instrument assembly/installation FAA approval of the test plan. It also requires that the FAA (or delegated DER) witness the test.

Successful EMI and Functional tests are complete by FAA DER approval of the documented results. With the approved results submitted to the FAA, this concludes the certification process with the issuance of the Supplemental Type Certificate (STC).

3.8 - Certification Procedures Manual

This SI Airworthiness Certification Procedures Manual is separated into sections to address all possible aspects of the science instrument as follows. If viewing PDF, you can click this link to open the manual: Volume 3: Observatory Airworthiness Manual.

Section 100: Introduction
This section is an introduction to certification, methods, and role of the participants. A short list of steps as well as an overview of the review process is also included.

Section 150: Data Submittals
This section addresses the content of the data submittals to the FAA.

Section 200: Documentation
The first important aspect of certification is the documentation. Section 200 has examples of title blocks and information on a possible numbering scheme for instrument designers. It is not required that the procedures be strictly followed, but similarity between instruments is key to streamlining this certification process.

Section 300: Mechanical
This section is dedicated to outlining the mechanical drawings and analysis that will be required for each component of the instrument.

Section 350: Manufacturing
This section addresses some of the more specific tasks that will be required during SI manufacturing. It includes process specifications, discrepancy reports, and a sample test plan flow chart.

Section 400: Electrical
The electronics subsystems within the SIs are largely low power signal processing electronics. All SI electronics are nonessential equipment for aircraft operation and so certification involves simple safety concerns. This section of the manual provides guidelines for design, documentation, failure analysis, and testing of electronics components.

Section 500: Functional Hazard Analysis Functional
Hazard analysis is required for each science instrument, and the necessary FAA hazard reporting forms and examples are included in this section.

Section 600: Operational Procedures and Maintenance (Continued Airworthiness)
This section addresses the maintenance and operation of the science instrument. Maintenance, operations, and continued airworthiness are very much connected under FAR Part 121, and therefore sections 600 and 700 have been combined. This section provides some guidance and references for writing and maintaining a logbook and maintenance manual for the science instruments.

3.9 – Schedule of Submittals

Each team shall prepare a standard Gantt chart outlining the instrument certification schedule. The dates of submittals and expected approvals will be specified by each science instrument team and

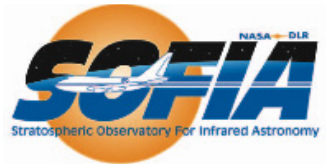
included in the Airworthiness Documentation Logbook by the science team. In general the SI team will submit several separate packages. The logical sequence for submittals is:

- Structural data – including drawings, stress analysis, drawing tree, load path and safety margin analysis.
- Drawings include materials, fasteners, welding specifications etc.
- Electronics data – including box to box cabling, power loading analysis, cable specifications and materials. See the SI Airworthiness Manual for a sample Gantt chart that includes typical submittal packages.
- System Safety Assessment – Includes functional hazard assessment, failure modes and effects, fault tree analysis.
- Operations procedures and continued airworthiness plans – Preparation for integration onto the aircraft (flow chart), standard safety procedures, operations procedures that pertain to safety (relief devices etc), storage plans, log book requirements etc.

WORKSHEET 3-1. SI Submittal Status Work Sheet

SI name - acronym Topic	Rev. level	USRA		L-3 / DER		FAA		NASA		UAL	
		Received	Approved	Received	Approved	Received	Approved	Received	Approved	Received	Approved
Drawing Tree											
Drawing List											
Detailed drawings											
Critical Structures Definition											
Cryogenic Reservoir(s)											
Pressure Relief system											
Cryostat											
Welding procedures											
Electrical wiring											
CWR components											
PI Rack components											
Installation of assemblies											
Kits: Detachable components; interconnect cabling											
Action Items											
RFAs											
Engineering Change Orders											
Nonconformance Reports											
Analyses											
Structural analysis											
Electrical power analysis											
System Safety Assessment											
Report											
Functional Hazard Analysis											
Failure Modes Effects Analysis											
Fault Tree Analysis											
Zonal Safety Analysis											
Proof & Burst Pressure Tests											
Plan											
Scheduling for test											
Final report											
Quality Assurance											
CQI designated											
QA plan											
FAA Form 8130-9 by CQI											
EMC/EMI compliance											
Test plan											
Results											
NASA Safety Analysis											
Preliminary Hazard Analysis											
PA10T - (NAME) - ###											
Operational Hazard Analysis											
Maintenance Manual											
Cryogen filling											
Operating instructions											
Ice plug abatement process											
Installation/removal process SI											
Installation/removal process CWR											
Installation/removal process PI Rack											
Electrical checkout (& grounding)											
Total Wt & CG @ install (CWR, TA balance, etc)											
Cart detailed design											
Weight and size											
Operation and ICD compliance											

Not part of approval process



CHAPTER 4

SSMOC Operations and SOFIA Observing Modes

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4.2 Flight Management 4-3
4.3 Pre-Shipment Logistics 4-6
4.4 Mission Ground Operations 4-6
4.5 Observing on SOFIA 4-18

4.1 - Yearly Scheduling of the SSMOC

The SSMOC will be scheduled on a Government Fiscal Year (GFY) cycle (i.e., October 1 to September 30 of the following calendar year). The schedule for a year will be finalized by August 1st of the GFY prior to the GFY being planned. The schedule's determination will be based on the science flights awarded, the aircraft and observatory maintenance required for that given year, and the constraints of the operating budget for that year. A scheduling program will be used which will take as inputs:

- Maintenance down times;
- Deployment constraints (or preferences);
- Any other SSMOC time constraints;
- Prioritized list of investigator teams with SI's to be used;
- Each investigator team's set of preliminary objects.

The scheduling program will assist the Operations Controller and the Project Scientist in scheduling the science flights for a year. The year will be divided into flight series or missions, with each normally some multiple of a week in duration for ease of installation and removal of science instruments. Each mission will have one installation of a science instrument (or a suite of science instruments mounted simultaneously) and one de-installation at its conclusion: The science instrument defines the mission. The science instrument could be a facility class instrument (FSI), a principal investigator class instrument (PSI), or a special class instrument (SSI). The FSI will be managed and supported by SSMOC personnel, the PSI and SSI by Principal Investigators (PI's) from the science community. Both the FSI's and PSI's could have a number of different investigators called Guest Investigators (GI's) using them within a single mission, and all science instruments could have a number of missions within one year. The final SOFIA science flight schedule will optimally group the observations, the investigators, and the science instruments into missions, which are scheduled so the highest priority astronomical objects of interest can be observed for the length of time required. The need for a deployment (or deployments) will be assessed and if necessary will be scheduled.

****** COMMENT *** See 3.2.7 below? Where is this?***

The scheduling task for all the SSMOC activities resides in the Operations Control Center of the SSMOC (see 3.2.7), with inputs from the SSMOC management team and all the SSMOC functional groups. Once the annual schedule has been determined, it will be reviewed by the SSMOC management team and NASA, and once approved placed on the SOFIA website. This then is the master schedule — a 12-month plan with all the science flights, science instruments, investigators, deployments (including ferry flights), maintenance, and holidays blocked out. In addition to this, there will be intermediate and operating schedules for each mission. The intermediate schedule for a mission is prepared by the Operations Control Center 90 days before the start of a mission, showing dates and approximate take-off times for the flights in the series. This schedule will

also have an estimate of the number of investigators who will participate and their approximate arrival and departure times (this includes the members of the PI team). At this stage a contingency plan is developed as a back-up in case the science instrument for the mission is not found to be ready during its scheduled reviews. The operating schedule for the mission is prepared by the Operations Control Center 30 days in advance of the series with details such as the flight plans (including flight take-off and landing times), the investigators (including their dates of arrival and departure), the logistics requirements (e.g., cryogens and shipping), and telescope configuration requirements (e.g., tertiary mirror). A readiness inspection of the PSI's and SSI's will be made either by a visit by a SSMOC scientist to the PI's institute or through a report by the PI showing the SI's performance characteristics. If the science instrument is not ready at 30 days prior to the mission, and is considered not likely to be ready for the mission, the back up plan for the mission may be activated. (This may mean moving a facility class science instrument's mission forward.) The coordination of the flight planning for a given mission (i.e., the flight plans given to the Operations Control Center for scheduling purposes) will be the responsibility of the PI of the science instrument for the mission flying PSI's and SSI's, but will be the responsibility of the SSMOC science coordinator for a FSI mission.

The first two years of operations will consist of a total of 1,200 SFH (Successful Flight Hours at or above 41,000 ft in altitude). In a normal year, after the second year of SOFIA operations, there will be a minimum of 960 SFH per year required, which translates to 137 successful science flights per year with each flight consisting of about 7 hours at altitude. If a total Science Effectiveness of 0.78 is used (see the Overview for this section), then to achieve 137 successful science flights about 4 flights per week must be planned and assigned to a science team over a 44 week period (the period remaining in a year after taking into account maintenance, weekends, and other down-times for the observatory). Hence, the peer review committee will assign a total of 176 flights to the science community each year, which will assure (with 80% confidence) 137 successful science flights per year.

Typically, a year will contain about 20 missions, with a total of about 50 investigator teams. This means, on average, each mission will last two weeks and will support 2 to 3 investigator teams.

4.2 – Flight Management

4.2.1 - Flight Planning Process

Flight planning and scheduling represents a unique problem for SOFIA. The visibility of an object depends on where and in what direction the Observatory is flying. Contrary to satellite missions the Observatory is also affected by weather conditions (wind, cloud cover, precipitable water vapor) and by airspace restrictions.

The zero fuel weight of the Airborne Observatory will be about 366,000 lb. If this is achieved, then in order to maximize successful flight hours within each flight, science research flight profiles will be either one of the following: Flat Flight Profile:

0.5 hrs climb; 7.0 hrs at 41,000 ft; 0.75 hrs descent

Step Flight Profile:

0.5 hrs climb; 2.55 hrs at 41,000 ft; 0.1 hrs climb; 2.6 hrs at 43,000ft; 0.1 hrs climb; 1.65

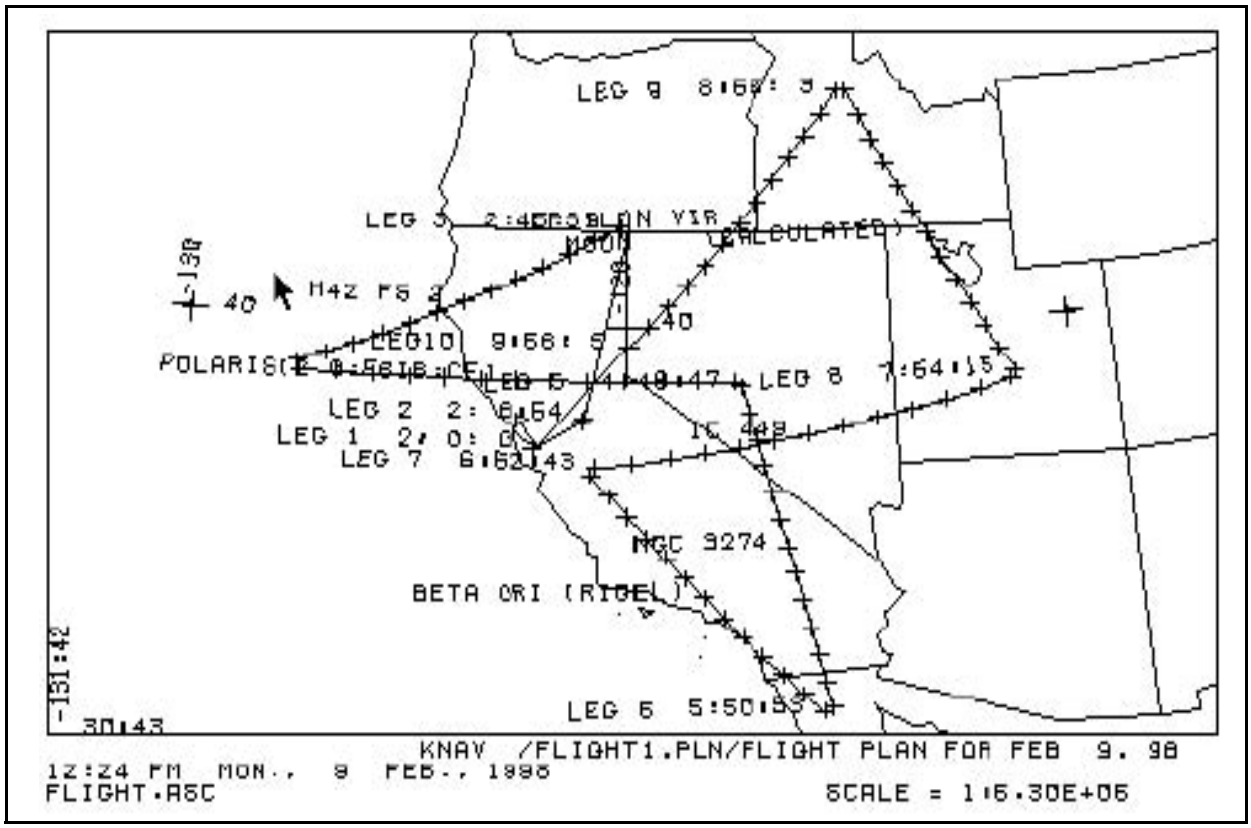


Figure 4-1. Typical Flight Plan from Moffett Field

Figure 4-1 shows a typical flight plan for a flight from Moffett Field. It shows seven observing legs, each about an hour long. Observing legs can vary in extent, from about 10 minutes to 4 hours each. Hence, the number of astronomical objects observed in one flight can range from about 2 to 16, but with an average of about seven. Normally, at least one object in a flight is a calibrator. This is a well-characterized object, so its measurement will calibrate the data for the whole flight.

4.2.2 - Flight Planning Software

The flight management infrastructure (FMI) is under development by ISD and NASA Ames Code I. The purpose of the FMI is to develop, arrange, optimize and execute aircraft flight legs, in order to enable successful execution of a prioritized list of observations.

The FMI contains four components:
- A manual flight planner
- A flight executor
- A cycle scheduler
- An automatic flight planner (currently an R&D-project)

The manual flight planner is functionally similar to KNAV, which was used on the KAO, but completely re-designed. The flight planner plans a flight for a given date taking a set of targets and observing times (exposure time plus overheads), a model for wind and water vapor, observing altitude and fuel consumption, as well as any flight restrictions like restricted airspace or established airspace routes. The goal is to construct a flight plan, which observes each target for the requested time and minimizes dead legs (times when no astronomical target can be observed). The Flight Executor is in-flight software that executes a flight plan constructed by the flight planner. The cycle scheduler is a software tool needed for gross scheduling of a whole observing cycle. The automatic flight planner is an artificial intelligence project being developed by NASA Ames Research Center's Code IC.

The FMI will be hosted in the SSMOC for planning and simulation purposes, and on the SOFIA aircraft workstations for execution and re-planning.

Before every observing cycl,e the SSMOC management team will decide how many engineering flights are needed and how much observing time can be supported. They will decide what instruments are available, and find out when and how much observing time each PSI/SSI team can maximally support. After the Time Allocation Committee (TAC) has ranked the proposals and made their recommendation for time allocation, the SSMOC scheduler will use the cycle scheduler to do a preliminary block schedule. This schedule will show when each instrument will be on the telescope and for how long, but without any detailed flight planning.

SSMOC personnel will do all the flight planning for FSI instruments using the manual flight planner. General investigators, which have been allocated time by the TAC, are required to file a detailed observing plan and a complete set of Astronomical Observation Requests (AOR). The DCS provides tools for filing the observation plan and associated AORs. The flight planner at SSMOC will use the AORs (and any additional constraints specified in the Observing Plan) to create optimized flight plans initially using the manual flight planner. A flight with an FSI instrument will typically contain targets from more than one project and more than one general investigator.

PSI/SSI instrument teams will do their own flight planning using the same manual flight planner that the SSMOC uses. The teams can, however, optimize the schedule within all the projects allocated to their particular instrument without having to fill in AORs or detailed observation plans.

The manual flight planner creates flight plans for United Airlines (UAL), which UAL can pass over to air traffic control. UAL needs a list of waypoints, with altitude, aircraft headings, true wind speeds and the amount of fuel remaining at each waypoint. The manual flight planner also creates flight plans for the In-flight Flight Series Director, as well as for the observer. These flight plans show the airplane heading at the beginning of each leg, what targets are observed and for what duration. They also list observing mode, guide stars, and the telescope elevation and cross elevation as well as when a field rotation update is needed. Due to inaccuracy in long-term weather predictions, the flight plan will be adjusted the day before a flight, and the manual flight planner is designed so that flight plans can be changed during flight.

4.3 - Pre-Shipment Logistics

(Location of future shipping and receiving information, and other pre-arrival logistics arrangements with the SSMOC – and points of contact.)

4.4 - Mission Ground Operations

4.4.1 - Overview of SI Team Integration into SSMOC Operations

A mission or missions is normally a multiple of a week in length and is defined by the science instrument (or the suite of science instruments mounted simultaneously) to be used. The science instrument could be a FSI, PSI or SSI (see above). In the case of the FSI, SSMOC scientists and technicians will ready the science instrument for flight. In the case of the PSI and SSI, principal investigators (PI's) from the science community must arrive at the SSMOC between one and two weeks before the first flight to ready their instrument for the mission. General investigators (GI's) who will use the science instruments (whether a FSI or PSI) will arrive at the SSMOC probably a few days before their first flight, to use the data center, familiarize themselves with the airborne observatory, and finalize their observing strategies. The near to final flight plans for the series would have been sent to the SSMOC, or generated by SSMOC scientists (see 4.3.1), 30 days prior to the first flight of the series.

Below is the sequence of events an investigator will follow within a mission (assuming a PSI mission):

a) Upon arrival at the SSMOC, the SSMOC science coordinator will show the PI/GI the facilities, especially the PI labs, PI/GI offices, telescope/MCCS simulator, data center and final flight plan-

ning facilities. The PI/GI will be introduced to the in-flight director for the mission, who will help coordinate the PI/GI science team with SSMOC operations, education and public outreach, and mission operations and support, aircraft operations and support, and the continuous improvement programs during the mission. The in-flight director will make sure the Observatory (especially the telescope) is configured correctly for the PSI as per the PI's written instructions on file, which have been re-confirmed by the PI for that particular mission.

b) After the PSI has been assembled and readied for the mission in a PI lab (usually a weeklong process), the PI team will be assisted by flight mission crew in integrating the science instrument into the airborne observatory via the telescope/MCCS simulators. This will occur a few days before their first flight. In this way, the SSMOC mission crew will be familiarized with the science instrument interfaces to the telescope and MCCS before the first flight.

c) On the first flight day of the series (normally a Monday), the science instrument will be attached to the telescope on the aircraft and integrated with the aircraft, MCCS, and TA systems with the help of telescope and computer operators, TA technicians, aircraft mechanics, and an airworthiness engineer. A high-fidelity simulation of the actual flight set-up sequence will be performed on the ground to test all aspects of the integrated system.

d) About 90 minutes before each flight of the series, the mission director will convene a pre-flight briefing with all flight personnel to summarize mission sequence and objectives for that flight.

e) In a morning meeting after each flight, the mission director will debrief (in person or in a mission report) aircraft, mission system, and science representatives on how the airborne observatory performed in flight. The meeting will be chaired by the aircraft schedule and planning controller. Where appropriate (possible), necessary corrections will be made prior to the next flight

f) After the last flight of a mission (usually on a Friday morning), the SI team will supervise the de-installation of the SI. The lab where the team assembled the SI will be available for end of series calibrations and disassembly of the SI required before shipping.

4.4.2 - SI Check-out in the SSMOC

Installation of a science instrument (SI) on the observatory will start with installation on the TA/MCCS simulator in the SSMOC laboratory. This procedure is required for all SI's and will occur one to a few days prior to each installation on the aircraft. An authorized and certified technician will inspect the completed simulator installation and describe any changes that will be required to obtain airworthiness approval for the subsequent installation aboard the aircraft.

Transportation of the SI from the PI lab to the TA simulator lab, and subsequently onto the aircraft, will be facilitated by a SSMOC-provided cart designed especially for the purpose of transporting and mounting the SI on the TA and the TA simulator. It is assumed that no more than one or two SSMOC technicians will be required for this effort. This cart will be designed to correctly

distribute loads to the aircraft floor for the heaviest allowable SI (600 kg) and will enable passage through the aircraft passenger door with the largest allowable SI. If the fully assembled SI is larger than the passenger door, then the reassembly of the SI inside the aircraft must not add more than 30 minutes to the nominal SI installation time.

4.4.2.1 - TA/MCCS Simulator Procedures

The TA/MCCS Simulator will aid in determining or verifying:

a) the mechanical and vacuum interfaces between the TA and SI

b) the optical alignment, focus, and boresight of the SI with the telescope

c) the mechanical, electrical, communication, and protocol interfaces with the MCCS

4.2.1.a Mechanical Interface

The TA simulator will duplicate all mechanical, vacuum, and electrical connections required to fully operate the SI in flight on the SOFIA airborne observatory. Hence, the physical layout of the SI flange assembly, the vacuum manifold, the MCCS patch panel, and the cable drape and connector flanges will be identical to that on the aircraft. The TA simulator mounting flange area will be an exact duplicate of the SI mounting flange area on the TA. An instrument rotator identical to that used on the TA will be available for use with the TA simulator.

Although the simulator will duplicate the TA and MCCS interfaces as accurately as possible, it will not duplicate the physical constraints associated with the ceiling or TA counterweight assembly, as these lie well outside the confines of the currently defined SI envelope. The simulator will have a floor clearance similar to that of the TA caged at 40 degrees elevation. The simulation of the floor clearance for other telescope orientations and SI rotations will be accomplished using several large plywood shims which can be inserted to approximate the location and orientation of the aircraft floor for extreme positions. This method is required because the simulator is stationary (i.e., it has no equivalent of the hydraulic bearing on the TA) and cannot reproduce the TA azimuth, elevation, and line-of-sight motions. Hence, final verification of all floor clearances will be done on the aircraft before the TA, with the SI attached, is uncaged.

The TA simulator will duplicate the vacuum manifold and pumps that are on the actual TA and aircraft so that the investigator can pump on the SI cryogens as needed. There will be space reserved for a closed-cycle-cooler compressor and closed-cycle-cooler lines to be included in the simulator and TA cable drape. The relative placement of the compressor and its lines will be the same as on the aircraft.

4.2.1.b Optical Alignment, Focus, and Boresighting

The TA simulator will be a single structure with a duplicate of the telescope mounting flange at one end and a tertiary mirror and alignment source fixture at the other end. The beam line from the alignment source fixture to the tertiary will form a 90 degree angle with the beam line from the tertiary to the SI flange and will reproduce the orientation of the telescope at 40 degrees elevation. However, the physical separations of the SI flange, tertiary, and alignment source fixture will be 1/3 to 1/2 the nominal TA separations, so that the simulator will have an overall length of only two to three meters.

Three sources will be available for use in alignment on the simulator: a small laser or telescope; a broadcasting source (hot plate); and a focused source (portable collimated light source, PCLS). The first will be used primarily at the SI flange to verify the alignment of the simulator itself (this may be the same device that is used for TA alignment). The second will have an IR black surface, which operates at approximately 100° Celcius. The third will use a small Cassegrain telescope and a quartz lamp to deliver both visible and IR radiation to the focal plane. Its focal range will accommodate all back focal distances allowed for the SI (-30 cm to +90 cm from the SI flange). Both the latter two sources will use circular chopper wheels and subtend a solid angle equivalent to that of the oscillating secondary mirror of the TA. They will be able to accept phase and frequency from the SI electronics (standard TTL) or synchronize with an internal clock and provide a reference output. The operational frequency range of the hot plate and PCLS choppers will be 5-10 and 5-30 Hz, respectively.

Since access to the TA cavity during installation is highly restricted, all SI alignments will be done on the simulator. In order to transfer alignments from the simulator to the TA, several boresight boxes (BSB) will be provided for use by the investigators. A BSB will be mounted on the SI, in front of the SI window, before installation on the TA simulator. This BSB will remain attached to the SI throughout its mission. Hence, at least two boresight boxes will be required: at any time one will be on the TA with the current flight experiment while the other is being used on the simulator by the next SI. The BSB will be mounted internal to (aft of) the SI flange and the SI will be mounted external to (forward of) the SI flange. The vacuum seal between the BSB and the SI will be made with an o-ring. The BSB will form a vacuum seal with the TA using either bellows couplers or a 41-inch diameter plate and o-ring seal. In the former case, access to the SI flange area is required for installation of the bellows coupler. In the latter case, the 41-inch flange plate will be transported from the simulator to the TA as part of the SI/BSB assembly.

Each BSB will contain a flip mirror and an optical CCD camera. When the flip mirror is “engaged,” light is reflected into this optical CCD camera; when the flip mirror is removed from the beam line, light passes directly through the BSB and enters the SI through its window. The BSB will have a means of adjusting the CCD path length to accommodate the allowable range of back focal distances for SI.

Alignment:

This mechanical alignment orients the SI so that its field of view is centered on the secondary mirror of the telescope. For this procedure the chopped hot plate is mounted on the TA simulator (see above) and the flip mirror in the BSB is removed from the light path. The SI detects the signal from the hot plate, which is maximized by tilting/positioning either the SI or a mechanism which is an external or internal part of the SI. This alignment is the sole responsibility of the PI team; there will be no adjustment made to the nominal TA alignment to accomplish this task. Once the SI alignment is optimized, this tilt/position will be locked down and will remain unchanged for the duration of the mission. (Note: Some investigators may develop SI with no provision for such an orientation adjustment. Such SI will still use the simulator to verify that their (fixed) orientation relative to the secondary is adequate for their experiment.)

Focus:

This adjustment ensures that the optical focus for the TA will coincide with the infrared focus for the SI. For this procedure, the PCLS is mounted on the TA simulator and the flip mirror in the BSB is initially removed from the light path. The focus on the collimator will be adjusted until a small (few arcsecs) point-like source is minimized in spatial extent or gives maximum signal on a single pixel. Without changing the PCLS (so the image in the SI remains focused), the flip mirror in the BSB is engaged and its optical CCD camera is adjusted until its image is focused. This focus setting on the optical CCD camera is then locked and remains unaltered for the remainder of the mission.

Boresighting:

The boresight procedure maps the IR focal plane onto the optical focal plane for use in pointing and guiding via visible (or near IR) stars. For this procedure, the PCLS is mounted on the TA simulator and the flip mirror in the BSB is initially removed from the light path. Once the SI is aligned and focused (in that order), the boresight or 'hot spot' of the SI is located by tilting the PCLS to illuminate a particular pixel on the detector array. This can be done directly in the case of two-dimensional imaging arrays (i.e., simply move the source to the desired location) or indirectly (i.e., maximize the signal on a particular pixel). Once the IR radiation from the PCLS is at the desired location in the focal plane, the BSB flip mirror is engaged so that the image falls on the optical CCD camera and the location of the optical image (which is coincident with the IR image) is recorded.

This completes the optical alignment procedure on the TA simulator. Knowledge of the proper alignment, focus, and boresight for each SI are the responsibility of the PI team.

Other Tasks:

An instrument rotator plate can be used with the simulator to determine whether the boresight, wavelength, or other parameters of an SI depend on rotation angle. If a particular SI does not use

the rotator plate, similar effects due to changes in TA elevation could be investigated by physically removing and reinstalling the SI in different orientations. If the boresight varies with rotation angle, it is the responsibility of the PI team to fully characterize or remove these effects so that the inflight focal plane imaging system can be operated in a simple and straightforward manner.

The simulator will allow polarizing grids to be inserted in the optical path between the simulator sources and the SI. The acquisition, installation, and use of appropriate grids will be the sole responsibility of the individual PI teams.

The simulator will have a bent optical path (90 degrees) with a single, reflective tertiary. Neither the dual tertiary nor the focal plane imager on the TA will be duplicated on the simulator (other than mechanical interferences). In conjunction with the facility rotator plate, the simulator could be used to measure the polarization of a beam splitter or mirror as a function of angle.

4.2.1.c MCCS Interface

The simulator will possess an interface patch panel and cable drape identical to that used in flight. All electrical connections between the SI and the MCCS will be physically present and the communication protocols between these two systems can be verified. The simulation of MCCS responses to SI commands will be as faithful as possible. For example, the MCCS indicator of TA stability and the transfers of housekeeping data will be fully operational, although the buffer contents for the latter will either be 'playbacks' of old flight data or 'dummy' data of some sort. On the other hand, the nod command for the TA will produce a status change in the MCCS, but will not be coupled to the alignment sources, so there will be no physical change in their output.

Weight and Balance:

Only the weight of the SI is measured on the ground. No determination of the SI c.g. is carried out in the TA simulator lab. The SI c.g. is determined in an automated fashion after SI installation on the TA.

4.4.3 - SI Installation on the Aircraft

After the SI has been checked out on the TA simulator, it will be installed on the aircraft, usually on the morning of the first flight day of the mission (i.e., usually Monday morning). The deinstallation of the previous SI will typically occur on the morning after its last flight (i.e., the morning of the previous Friday). The mechanical mounting of the SI on the TA will require the assistance of two TA technicians (with the aid of an SI cart), but will be primarily the responsibility of the PI team. Concurrently, two aircraft mechanics will load the science racks onboard the aircraft, secure them in the desired locations, and install the associated seating.

After mechanical installation is complete, the SI will be connected to all of its cables, hoses, and electronics; cryogens will be filled as needed; and vacuum pumps will be turned on as appropriate. That is, the experiment will be placed in operational, flight-ready status. Although the TA technicians will assist with this activity, most of the interconnects (e.g., cable connections to the SI and the SI racks) and other details of this installation procedure will be carried out by the PI team, with review and signoff by certificated SSMOC technicians. This entire procedure should take no longer than 2 - 3 hours, since it would have been demonstrated in the TA/MCCS simulator.

Once the installation is complete and the SI is operational, the (two) installation technicians will place the TA balancing weights required for three-dimensional, rotational balance of the TA/SI package. This will be done by connecting strain gauges between the aircraft and telescope assemblies, rotating the telescope to several elevations, and using associated MCCS-based software to solve for a unique static solution.

After the TA weights have been added, the RIS (Rotation Isolation System or TA bearing) will be activated and the telescope will be unbraked with the telescope at 40 degrees elevation. Then, as the telescope moves through all its angular degrees of freedom, the cable drape and floor clearances will be checked for interferences. The balance will be checked through the full elevation range of the telescope. For SI's using the instrument rotator plate, the balance of the telescope will be checked for all SI rotation positions with respect to the telescope. For SI's using the rotator plate, it is required that their center of gravity will be sufficiently close to their rotational axis that the TA fine balance system can compensate for SI rotation. The entire balancing procedure should take no longer than about 1 hour.

After the telescope balance is complete, an observing sequence will be run to exercise all interfaces and subsystems, to test for electrical interferences, and to look for any other potential problems. As many systems as possible will be activated, including the secondary mirror assembly, the telescope gyros, the telescope torque motors, as well as the RIS. The TA VIS (Vibration Isolation System) need not be activated. Small forces will be applied to the telescope (by hand) to test EMI interference from the torque motors. A simulated tracking routine will be used to check that all the correct MCCS signals are being sent to the PI electronics, and that the MCCS and TA (i.e., the secondary mirror) are receiving all signals from the PI electronics. In general this test period should take no longer than 1 hour, but could be much longer if problems are uncovered. (If such problems are in the SI, then the Observatory Director will make a decision whether to substitute a contingency mission using a facility SI.) This stage of the SI checkout would often be run in parallel with the cavity cooldown sequence (see below).

After installation is complete and all ancillary equipment is stowed, an airworthiness inspection of the set-up will be conducted by an aircraft mechanic.

4.4.4 - SI Data and the SSMOC Data Cycle System (DCS)

The SOFIA data acquisition and handling software is called the Data Cycle System (DCS). The DCS software is being developed as a distributed software effort. Rochester Institute of Technology (RIT) is developing the DCS Core (system architecture and user interaction) while UCLA (with assistance from IPAC) is designing the SOFIA archive. Additional DCS efforts are developed by the USRA Information System Development (ISD) and NASA Ames Code SSA. The whole DCS will be deployed at the SSMOC where it will be further developed and maintained.

Note: Although the SOFIA contract Statement of Work only required a simple summary science data archive, it was decided rather early in the development of SOFIA to provide a modern searchable complete archive. The SOFIA archive will store all raw data and any pipeline-reduced data from SOFIA science instruments. All FSI instruments will have data reduction pipelines, and pipelines will be added in the future for PSI and SSI instruments as resources allow. Additionally, the archive will accept reduced data contributed by the FSI, PSI, or SSI instrument teams and other qualified personnel (i.e., data taken in modes for which SOFIA-hosted pipelines do not exist). The Statement of Work also did not require automated operation of the instruments, but SOFIA has decided that selected modes of FSIs will be operated automatically via commands generated from astronomical observing requests (AORs). This document describes the details of these operation and archive additions.

4.4.5 - Minimum Science Capabilities

In order to ensure that the DCS development resources were properly staged, the DCS team prepared a list of minimum requirements - in May 2001. These minimum requirements were presented to and endorsed by the SOFIA Science Council and the SOFIA Science Steering Committee in summer 2001 and the NASA OSS Origins Subcommittee in May 2002.

The minimum Science Capabilities at the time of ORR will be:

1. Electronic Proposal preparation tool (both for FSI and PSI instruments)

   a. Observing time estimators (web based tools for FSI instruments, tables and graphs for PSI instruments)

   b. AOT/AOR editors and Observation Planner for FSI instruments, visibility estimation will initially be done by tables and graphs

   c. Proposal handling software

2. Flight Planning and Scheduling

   a. Manual at first, long term goal is a fully automated planner

3. In-flight Quick Look of science data

4. Data Pipelining of FSI data

a. Algorithms provided by instrument teams

b. Automation of pipelines implemented by DCS

5. Data Archive

a. Raw science data (including calibration data) to be archived for all science instruments. All raw data will be available in FITS. Ancillary data may be stored in the archive as Binary Large Objects (BLOBS)

b. Archiving of all HK data

c. Ability to search, browse, and retrieve all SOFIA data

- Access to the SOFIA archive will be through the web
- The archive will recognize and correctly handle proprietary data

d. Pipeline reduced, calibrated data for standard observing modes will be archived in FITS format

e. Mission/observer logs, flight plans, proposal information, audio and video data will also be archived

The science capabilities that have been deferred until after ORR are:

1. Planning and visualization tools

a. The minimum science capabilities provide simple editors for AOT/AOR generation and observation planning, but without interactive graphics interfaces for visualization.

2. Interactive Data Reduction

a. Instrument teams will provide interactive data reduction capabilities, but they may not be well documented and hence not very user friendly

b. The facility instruments available at ORR write their data in standard FITS. It is therefore expected that observers can export their data to common data reduction packages like IDL, IRAF or other reduction packages and interactively reduce their data. IDL, IRAF, CLASS and other commonly used reduction packages will be available at the SSMOC.

3. Pipeline reduction of PSI data

a. Raw PSI data (including necessary calibration data) will be archived. PSI data can therefore be pipeline reduced at a later date, if there is enough interest and pending allocation of resources.

4. Web-based integration time estimators for all science instruments

5. Quick Look analysis tools

a. For ORR and the first generation instruments, the instrument teams provide Quick Look analysis tools. A long-range goal is that DCS would take over Quick Look analysis tools (at least for FSI instruments) to provide a more uniform look and feel for in-flight evaluation of data.

4.4.6 - Implementation of Minimum Science Capabilities

Table 4-1 gives a brief summary of how the minimum science requirements are being implemented, identifies who is contracted to do the work and when the products are being delivered. This assumes that all the interfaces between the core DCS, the DCS archive, science instruments, MCS and other software packages are fully defined and adhered to by all parties. DCS has developed a generic interface document (ref 8) and is developing ICDs with the MCS and each FSI to ensure that this will happen. PSI Instruments have fewer requirements; they only need to adhere to the required keyword list (Section 5) and provide a data manifest that defines the science and ancillary data to be archived. The DCS and its interactions with the science instruments, MCCS, and scientific users are shown schematically in Figure 4-2.

Table 4-1. Implementation of Minimum Science Capabilities

Minimum Science Capability	Software Products and Developer	Ready By
1. Proposal preparation and proposal handling	APT modification – NASA Ames Code SSA Observing time estimators for FSIs: ARC SS Handling & processing: DCS Core & Archive	Early 04 Early 03 Early 04
2. Flight planning and scheduling	Flight management software – USRA ISD and NASA Code IC	ORR
3. In-flight quick look	QLA-tools – instrument teams	Instrument commissioning
4. Data pipelining	Pipeline algorithms – FSI teams Pipeline automation – Core DCS	Instrument delivery
5. Data archiving	Data archive & browsers – DCS archive	Observatory testing

An implementation scheduled for deferred items will be developed at a later stage. Available staffing and budgets are not defined well enough at this time to develop realistic schedules.

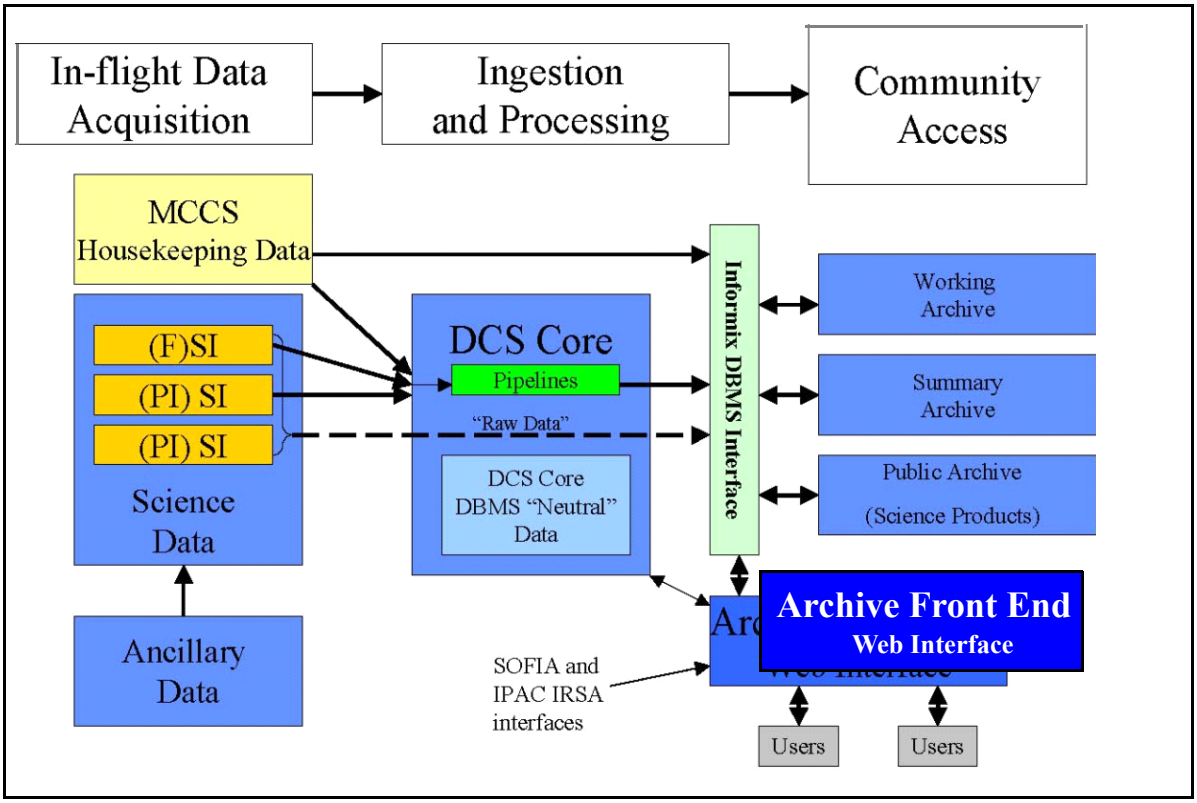


Figure 4-2. DCS Components and Interfaces

4.4.7 - Interfaces between Science Instruments, MCS and the DCS

All instruments connect directly to MCS using TCP/IP communication protocol through the MCS patch panel. It is therefore always possible to set up and execute an observation directly from the instrument console. PSI/SSI instruments usually operate in this mode, which means that an observer (General Investigator) has to learn the syntax of the instrument command language (which is different for every instrument) in order to do an observation.

For FSI instruments the observation control is done through the DCS. DCS provides an Astronomical Observation Template (AOT) editor, which allows a GI to fully specify an observation (i.e., all the commands for the telescope, trackers, and secondary mirror assembly, as well as all the instrument setup parameters) and write it out as an instrument neutral Astronomical Observation Request (AOR). The manual flight planner uses these AORs (together with any constraints from the associated Observing Plan) to create a flight plan. For an observer, a flight plan is simply an ordered list of AORs. In-flight these AORs are passed to a queuer/sequencer, which translates the AOR into MCS and Instrument commands and parses the commands to MCS and the Instrument through the instrument control. In practice both the AOT editor and the Queuer are likely to be run from the instrument console. The Queuer allows the observer to re-order the queue, add or

delete AORs in the queue, and pause, halt, abort or extend the AOR currently being executed. The AOT editor can be used to modify an AOR (or even create a completely new AOR), which can be inserted into the queuer for execution.

At the end of a flight all the Science Instrument data, and MCCS HK data will be archived. In order to identify which files need to be archived, each data provider will create a data manifest. A data manifest is an XML document with a list of data entries, which identifies who created the file and when, the type of the file, the size (or checksum) of the file and where it is located. The data manifest can also contain any number of error report elements. The error report elements are only created by the archiving software and are not generated by the data providers. Addition of an error report element to the data manifest provides a mechanism for recording processing errors while the archiving process is going on. Both MCS and Science instruments are likely to automatically update the data manifest each time a new file is created.

When the Observatory is physically connected to SSMOC via a high speed LAN, the DCS core will automatically collect these data manifests (presumably via a CRON-like process), and transfer them to the SOFIA archive, which will immediately start archiving the data from all the different data providers: MCS archive, science instrument data disks etc. The SOFIA archive will have data drivers for all common file types and these drivers will parse the information into the relational database. If a file type is not recognized, it will still be stored in the archive as a large binary object. This means that it can be retrieved from the archive, but that one cannot search on any information contained in the file. If the data provider later provides information of the file type it can be parsed and properly ingested into the relational database. PSI/SSI Instrument data will only be stored as raw data, but the archive will digest enough information from the data headers so that summary information of the PSI/SSI data can be stored in the archive. Any errors that occur during the archival process will be passed back to the data provider with automatic e-mail notification to the person(s) responsible for the data. In case of a fatal error (i.e., a file could not be archived), the file will also be copied to the DCS Data Store, until the SSMOC archive scientist, or a software engineer has investigated the reason for the transfer failure. The data file will also remain on the data disk, where it was originally created.

If the science data originated from a PSI/SSI instrument, the data cycle is completed once the raw data have been successfully ingested by the SOFIA archive and the DCS Core has sent an automatic e-mail to the PI and the SSMOC archive scientist that the data have been successfully archived. If the Science data originated from a FSI Instrument the DCS Core will automatically start pipelining the data. If the pipeline requires user interaction, the pipeline reduction will not commence until normal working hours, when the SSMOC personal arrives to start their daily tasks.

4.5 - Observing on SOFIA

4.5.1 - Observing Command and Housekeeping Interfaces

Chapter 1 of this handbook gave an overview of the Observatory sub-systems, including the Mission Control Sub-System (MCS) and the Telescope Assembly (TA). The SI computer/electronics physically connects to the MCS through the PI Patch panel near where the SI Racks are mounted in the Mission Control Area of the Aircraft Cabin.

There are two mechanisms for communication and data exchange between MCS and the SI system, the SOFIA Command Language (SCL) and data-definition XML files. SCL allows scientists and other Observatory personnel to control Observatory observations and to access other MCS software functions, controls, and services from onboard SI computers and Observatory workstations (i.e., consoles). Commands are entered by activating previously composed scripts (XML files) and through command-line interfaces and GUI selections. These SCL commands are passed to MCS where validation and translation into the appropriate direct commands to the telescope or other subsystem occurs.

As mentioned in Chapter 1, there are two exceptions to the rule that all SI Observatory control and monitoring is through the MCS: one exception is the direct interface to the three imagers (i.e., FPI, FFI, and WFI) digital outputs; the other exception is the direct link to the secondary Mirror Control Unit (SMCU) (see Chapter 2, “SOFIA Science Instrument ICDs” on page 2-1 about the TA_SI_04 ICD).

The MCS is also the collector and broadcaster of all Observatory housekeeping data. An SI computer can subscribe (using SCL) to receive a selection of this available housekeeping data to place in the headers of SI data files. All housekeeping (as SI data) is time stamped using the IRIGB connection to the MCS.

Details of SOFIA observing modes and how to use SCL (and an SI Data XML File) to implement these modes can be found in the SCL User Manual. Details on SCL protocols and XML file formats can be found in MCCS_SI_04, mentioned in Chapter 2 of this handbook. In this section, we only outline the observing set-ups and modes that will be supported through SCL at ORR.

4.5.2 - Observing on an Airborne Platform

The MCS, at the beginning of a flight, uses many aircraft and telescope attitude and position data inputs to estimate the relationship (transformation) between the gyro read-outs and sky coordinates. This transformation is perfected after the first pointing of the telescope in flight on a known source. This perfected estimation of the gyro to sky transformation allows for blind pointing to an accuracy of approximately 2 arcmins on the sky – the exact level depending on the time since the last sky update and the degree of the slew from the last sky update. Pointing accuracy is improved to about the 0.5 arcsecs level with the use of a track-star (of known sky position) close to the IR

source being observed - the closer, the better. Based on the image of a track-star, the MCS (with Tracker inputs) will correct pointing and update the gyro-to-sky transformation.

While observing a particular IR source, an Area of Interest (AOI) around a track-star is required by the Tracker to stabilize the pointing accuracy of the TA. This stabilization is carried out at low frequencies (greater than a few Hz). High frequency pointing stability is handled through the gyro servo control loop (in the TASCU – see section 1.4 - ”Mission Control Sub-System” on page 1-30), but slow gyro drift can cause the gradual loss of pointing accuracy if not corrected with visual reference points on the sky by the Tracker; these visual reference points can be provided by stars either in the FPI, FFI or the WFI – best accuracy is achieved when using the FPI.

Normally the Tracker works in two ways to stabilize pointing accuracy:

1) Positional stability by keeping a known gyro-offset from a “track-star” and the “Tracking-Position” (usually tied to the SI boresight) held constant.

2) ROF stability by viewing two “rotation-stars” simultaneously in one imager (usually in the WFI) to hold the angle of the line between them constant in rotation.

Both (1) and (2) need good positional information about the track- and rotation-stars. This is done by fixing (by a GUI) an AOI around each star so the Tracker can use these limited “areas of interest” to calculate the location of the centroids of the stars enclosed in them.

If the centroid of a “track-star” moves slightly in one direction, then the tracker will move the “Tracking-Position” in that same direction to maintain the gyro-offset between the Tracking-Position and the track-star. If the Tracking-Position is tied to a particular TA Reference Frame (TARF) position (e.g., boresight – i.e., if the tracking “boresight=yes” flag is in place), then the Tracker will signal the TASCU to move the telescope to keep the SI boresight fixed with the Tracking-Position. Thus, nothing would have appeared to move in the focal plane, but the Tracker and TASCU have steadied the IR source within the SI boresight.

If the centroids of the two rotation-stars move such that the rotation angle of the line joining them has changed, then the tracker will send this deviation to the TASCU, where an LOS correction will be made.

In addition, based on these corrections, and if the IR source being observed is declared “inertial” (i.e., the “inertial=yes” flag is in place), the Tracker will send to the TASCU modifications required to the gyro-readouts (which can be reset by the TASCU) so that the transformation between the sky and gyro frames is kept constant and correct. In this way, while inertially tracking, are re-calibrating the sky to gyro transformation automatically, and preserving the ability to blind point the telescope. NOTE: If the IR source being observed is not inertial (i.e., non-sidereal - e.g., a Solar System body), then must set the “inertial-no” flag, and no gyro to sky update will take place.

The above general description was for “centroid” type tracking. However, there is another form of tracking called “limb” tracking. This also can be accommodated by the Tracker with the addition of another AOI (i.e., in addition to those around a track-star, and two rotation-stars) placed on the limb of the extended object being observed (e.g., the moon).

4.5.3 - Set-ups and Observing Modes Supported at ORR

4.5.3.1 - Selecting and Perfecting SI Boresight

The SCL User Manual shows how an SI user can designate the SI boresight (as described in the SI Data XML file supplied to the MCS by the SI user) as the boresight to be used by the MCS to point the telescope (instead of the TA boresight or one of the imager boresights, for example).

This manual also shows how an SI observer can perfect the designated SI boresight (and SI array rotation w.r.t. the imagers – where applicable) in either the stare-mode or chop-mode (since some SIs must chop to detect a signal).

It is assumed that a particular SI boresight need only be perfected once within a flight-series, and probably at the beginning of the flight on the first flight.

Figure 4-3 shows the situation before a boresight is perfected. The SI array, as depicted in the SI Data XML file, is shown in white, including the location of the boresight pixel. This location is w.r.t. the TA Reference Frame (i.e.,TARF), as seen in the FPI. The real SI array is shown in yellow, however; so the real SI boresight is in another location w.r.t. TARF. Also shown in Figure 4-3 are the images of a track-star (with an AOI) and an IR source. (In the chop-mode, figures showing the sky, in Figure 4-3 and Figure 4-4, represent just one chopped image of the sky.)

Figure 4-4 shows first what happens after an observer requests the TA to move to an IR source, with the SI boresight as the designated boresight, and tracking enabled with the flag “boresight=yes”. Since the real SI array w.r.t. TARF is in another location, the real designated SI boresight in the SI array will not have the IR source in it. The observer then “tweaks” (i.e., moves) the “Tracking Position” in TARF, and with it “follows” the IR source on the FPI (because the telescope is moving). When the Tracking Position coincides with the Real SI Boresight, the observer will issue an SCL acknowledgement, and the MCS will update the location of the SI boresight (and thus array) in TARF.

If desired, the exercise can then be continued to perfect the determination of the alignment of the array with respect to TARF, by using a sequence of IR source “peak-ups” in the corner pixels of the SI array.

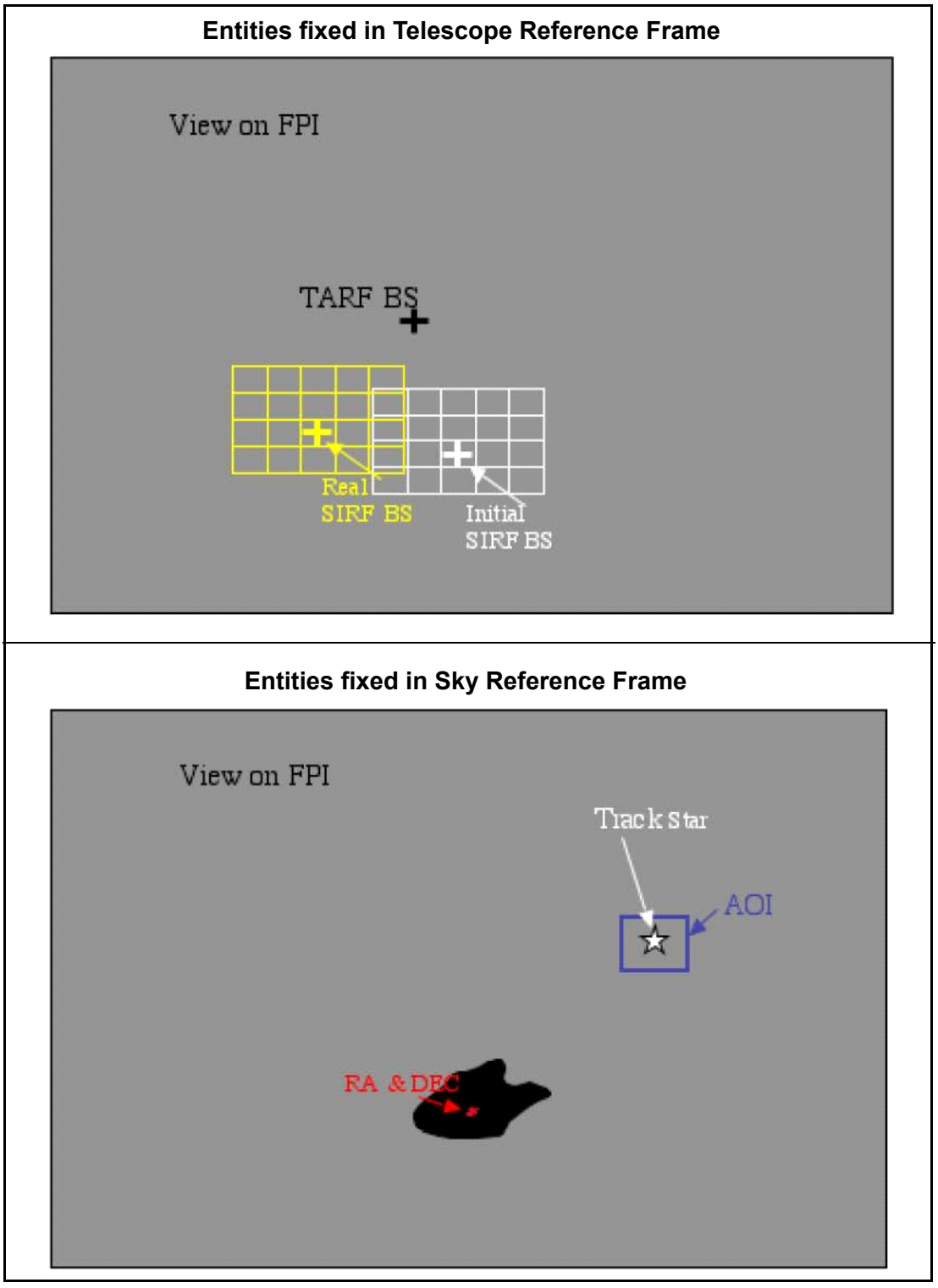


Figure 4-3. Set-up for Boresight Measurement

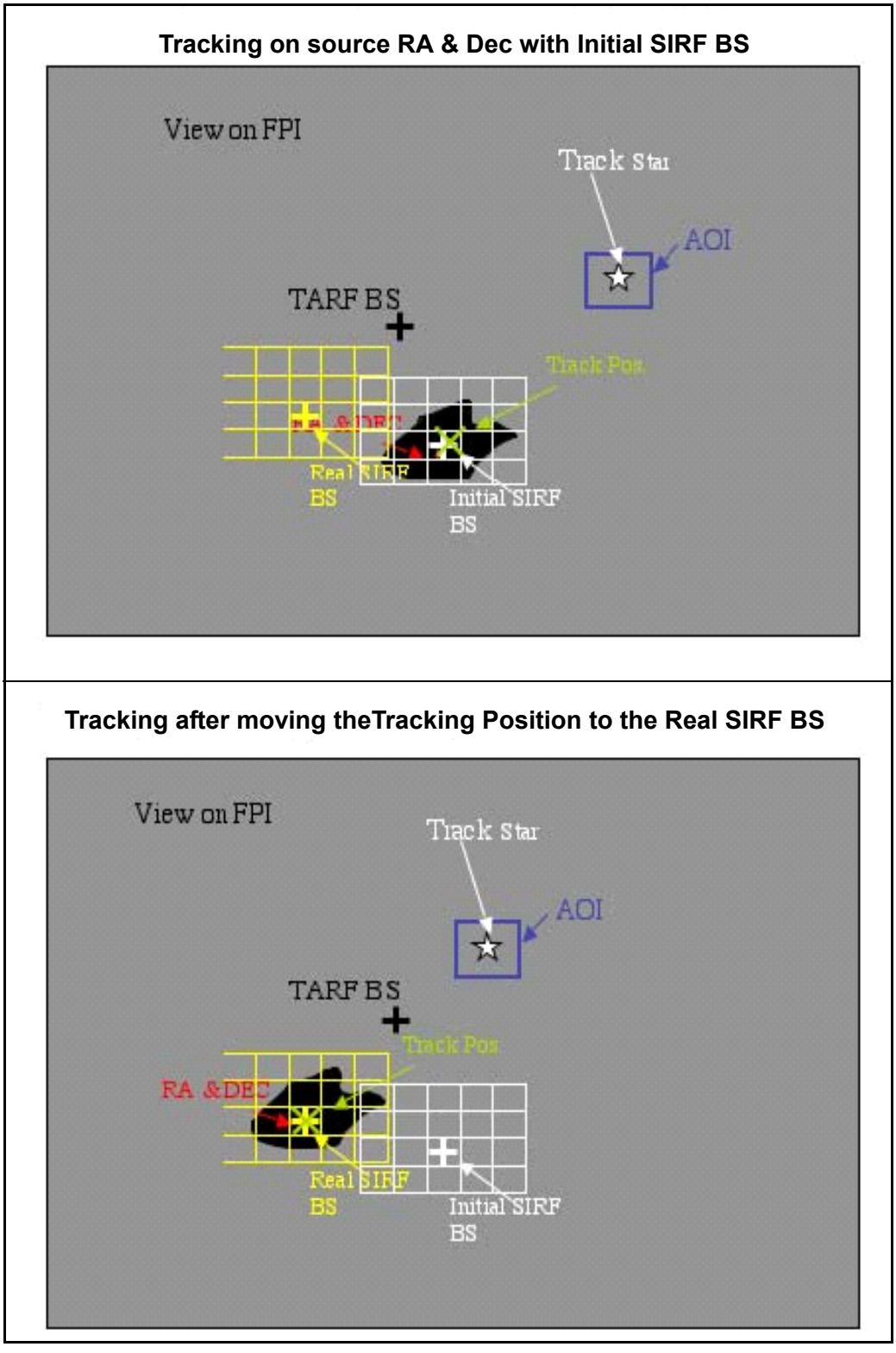


Figure 4-4. Measurement of SI Boresight

4.5.3.2 - Stare Mode

In this mode, the chopper (i.e., TCM) is centered and static (i.e., there is only one image of the sky in the focal plane), and the Observatory uses the designated SI boresight location within the focal plane to point the telescope. Since the SI boresight is the designated boresight, a command to the telescope to point at a particular RA and Dec on the sky will result in the telescope moving that particular RA and Dec into the SI boresight in the focal plane.

Once the gyros have been calibrated to the sky (at the beginning of each flight) and the SI boresight has been perfected (once per mission per SI reference frame configuration), the telescope on SOFIA should blind-point to an accuracy of ~2 arcmins (TBV), depending on the sky distance and time duration from the last verified pointing.

In order to obtain a "translational" pointing accuracy of about ±0.5 arcsecs on the sky, an observer must assign a track-star (with known sky coordinates) with each position to be observed. The closer the track-star to the object being observed, the more accurate the pointing, since ROF errors have less affect on translational pointing errors when the distance between the track-star and IR source is small. The track-star is called into use by defining an AOI around it, and instigating tracking (either through SCL commands or a GUI) once the observer (or Telescope Operator) has commanded the telescope to the position to be observed. The Tracker will maintain the known gyro-offset between the track–star and the object of interest throughout the stare-mode observation.

The pointing stability of the SOFIA telescope is still to be verified, but is expected to be close to 1 arcsecs RMS at ORR, improving to about 0.5 arcsecs RMS or better within three years of operations. Thus at ORR, may have a higher pointing accuracy than stability, which means the centroid of the object being observed is within about ±0.5 arcsecs, but that there is a pointing blur with an RMS value of 1 arcsecs. (Those of you with large diffraction-limited beams will hardly notice.)

Rotation stability (i.e., the stability of ROF), as well as translational stability, can also be monitored by the Tracker when two rotation-stars are chosen within the FOV of the WFI or FFI, and AOIs have been drawn around them. (However, rotation stability is monitored by the Tracker, only when the tracking keyword/attribute, "*inertial*", is set to "yes".) Note: rotation stability is expected to be on the order of ?? millidegrees RMS (TBV) with gyro pointing alone.

Stare-mode also includes tracking on non-sidereal objects, such as Solar-System bodies. Non-sidereal positions on the sky can be specified using an ephemeris file containing orbital parameters for a particular Solar-System object. (Note: while tracking on such sources, will not be updating the gyro to sky transformation; the tracking "inertial=no" flag will be set.)

4.5.3.3 - Nod (Beam-Switching) Mode

In this mode, the chopper (i.e., TCM) is centered and static (i.e., there is only one image of the sky in the focal plane), and the Observatory uses the designated SI boresight location within the focal plane to point the telescope.

SOFIA SCL and GUIs enable the observer (or Telescope Operator) to easily set up a series of positions on the sky (nod-positions or nod-beams), with tracking information (including AOIs) at each position, in a particular observing sequence (i.e., a "nod-sequence). The most common sequence is a two nod-beam sequence – often called beam-switching. Figure 4-5 shows a two nod-beam (A and B) sequence. The top figure shows the telescope pointed at nod-beam A, then the telescope moves to nod-beam B in the bottom figure. This sequence can be repeated any number of times – and can be extended to more beam positions. When the telescope moves to the next nod-beam in a sequence, the telescope will automatically start tracking as pre-prescribed for that nod position.

It is possible to also map while in nod-mode. SCL commands allow an observer to map, using pre-defined offsets, in just one nod-beam or simultaneously in any number of specified nod-beams.

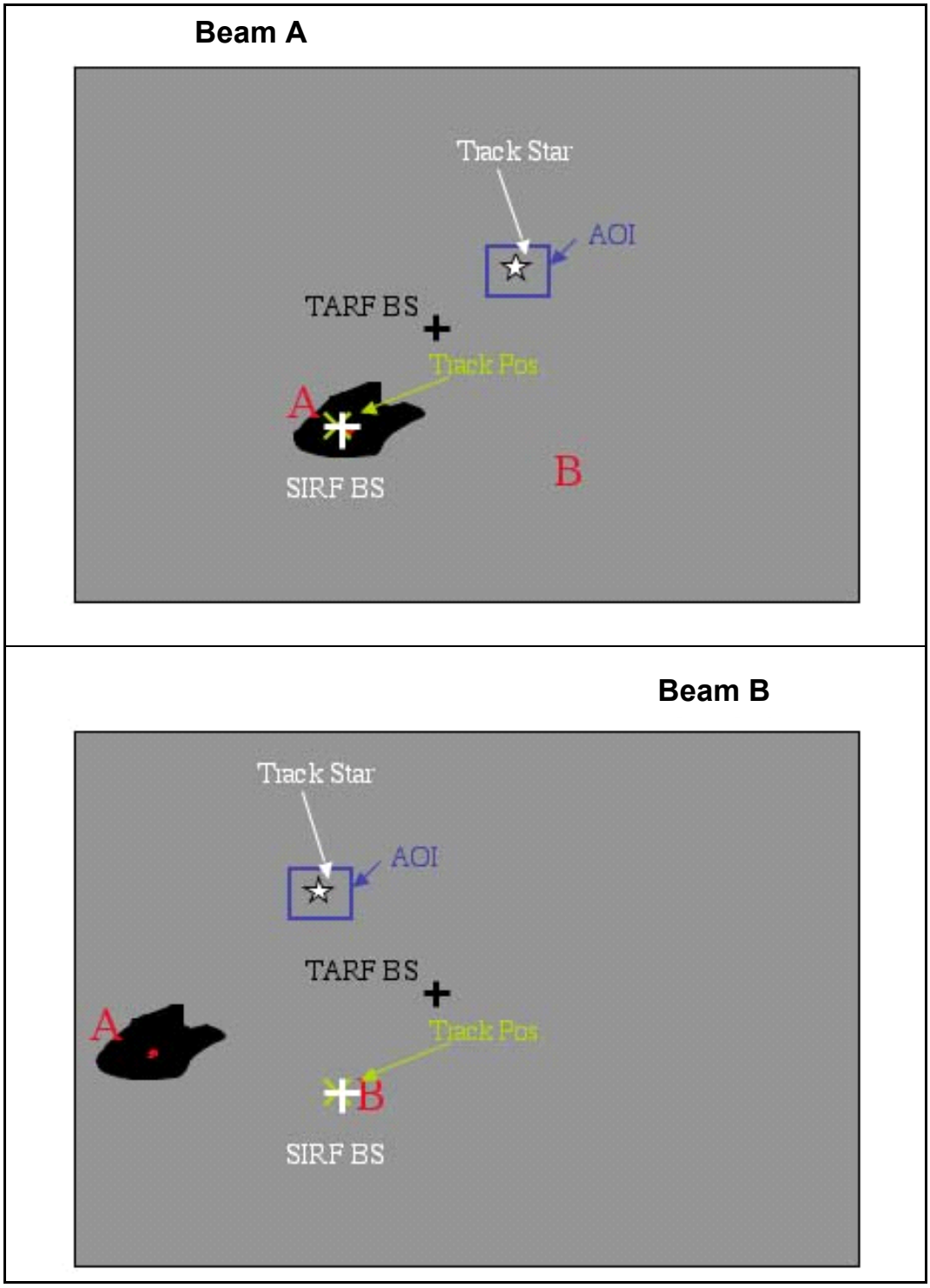


Figure 4-5. Nod-Beam Sequence of Two

4.5.3.4 - Chop Mode

In this mode, the chopper (i.e., the TCM) is under a control loop tip/tilt oscillation. There are 5 basic modes for the chopper:

1) Internal Two-Point Chop: This mode is driven by a TTL signal internal to the Secondary Mirror Control Unit (SMCU). A two-point chop has "plus" and "minus" endpoints. The SI data computer synchronizes to the chop by receiving, through the SI/SMA Junction Box, the same TTL signal that is driving the chop (see the ICD TA_SI_04). Chop parameters that can be set via SCL (or GUI) in this chop-mode are: Chop Amplitude (i.e., separation of the "plus" and "minus" endpoints on the sky in arcsecs); Frequency of Chop (in Hz); Tilt-Offset (in arcsecs on the sky); Tip-Offset (in arcsecs on the sky); and Chop Angle (in degrees).

2) External Two-Point Chop: This mode is similar to mode (1) except the TTL signal driving the chop comes from the SI electronics. This signal is passed to the SMCU through the SI/SMA Junction Box (see ICD TA_SI_04). Chop parameters that can be set via SCL (or GUI) in this chop-mode are: Chop Amplitude (i.e., separation of the "plus" and "minus" endpoints on the sky in arcsecs); Tilt-Offset (in arcsecs on the sky); Tip-Offset (in arcsecs on the sky); and Chop Angle (in degrees). Frequency is set by the SI TTL signal

3) Internal Three-Point Chop: This mode is driven by a TTL signal internal to the Secondary Mirror Control Unit. A three-point chop consists of three, colinear settling points, "plus", "zero" and "minus", in a chop cycle. The SI data computer synchronizes to the chop by receiving, through the SI/SMA Junction Box, the same TTL signal that is driving the three-point chop (see the ICD TA_SI_04). ICD TA_SI_04 shows how a two-state TTL signal drives a three-state chop. Chop parameters that can be set via SCL (or GUI) in this chop-mode are: Chop Amplitude #1 (i.e., separation of the "plus" and "zero" chop-points on the sky in arcsecs); Chop Amplitude #2 (i.e., separation of the "zero" and "minus" chop-points on the sky in arcsecs); Frequency of Chop (in Hz); Tilt-Offset (in arcsecs on the sky); Tip-Offset (in arcsecs on the sky); and Chop Angle (in degrees).

4) External Three-Point Chop: This mode is similar to mode (3) except the TTL signal driving the chop comes from the SI electronics. This signal is passed to the SMCU through the SI/SMA Junction Box (see ICD TA_SI_04). Chop parameters that can be set via SCL (or GUI) in this chop-mode are: Chop Amplitude #1 (i.e., separation of the "plus" and "zero" chop-points on the sky in arcsecs); Chop Amplitude #2 (i.e., separation of the "zero" and "minus" chop-points on the sky in arcsecs); Tilt-Offset (in arcsecs on the sky); Tip-Offset (in arcsecs on the sky); and Chop Angle (in degrees). Frequency is set by the SI TTL signal.

5) External Analog Chop: This mode is completely driven by the SI electronics, within the chop amplitude limits and intrinsic time-constant limits of the chopper (i.e., 10 arcmins (TBV) on the sky and 10 milliseconds (TBV), respectively). This mode requires the SI electronics to send and receive analog signals through

the SI/SMA Junction Box “R” and “S” input and output connectors so that the SMCU will drive rotations about the “R” and “S” axes in proportion to the voltages in the analog input signals (see TA_SI_04).Synchronization is through the output analog signals from the SMA sensors.

Figure 4-6 illustrates the chops described in (1) through (4). When using the two-point chop, there are two images of the sky in the focal plane. There are three images of the sky when using three-point chops. Figure 4-6 illustrates the view from the FPI (or SI) for a two-point chop.

Note: Since the FFI and WFI are NOT viewing the sky through the Secondary Mirror their view of the sky is unchanged from the no-chop view.

When the SMA has been initialized at the beginning of a flight, and a chop mode is to be used, the MCS will run through a short Chop Calibration routine, so chop parameters sent to the SMCU will drive the chopper as requested.

After SMA calibration, when using chop modes (1) through (4), the MCS automatically knows where the “plus”, “zero”, and “minus” images of the sky are in the focal plane with respect to the “no-chop” position of the sky in the focal plane. BUT when an observer uses the Analog Chop Mode [i.e., is mode (5]), the MCS has no idea where these chopped images are, unless the SI computer gives this information. How this information is passed to the MCS is still TBD, but there are a number of options. (If a user plans to use the analog mode for chopping, that user should contact the SSMOC to ascertain what inputs the MCS needs from the SI in order to point the telescope.)

For chop modes (1) through (4), the MCS creates “plus”, “minus”, “zero” (where applicable) and “no-chop” versions of the SI boresight and assigns to the “chopped images” of the IR source (and its track-star) similar titles. The fictitious boresights are used when the track-star is in the FFI (or WFI). The fictitious locations on the sky of the images of the IR source (and its track-star) are used when the track-star is in the FPI. Figure 4-7 and Figure 4-8 illustrate this MCS scheme. The fictitious boresights are used in both the FPI and FFI cases to determine the positions of the reference beams of a chop as well as the position of the actual SI boresight. In the second figure of Figure 4-8, for example, the “SIRF BS (minus)” lies on the (un-chopped) sky position of the reference beam when the actual SI boresight is on the plus image of the IR source in the focal plane of the telescope. All chop-beam locations on the sky are recorded in MCS Housekeeping.

The process to set up the chop mode is simple – no matter if the track-star is in the FPI or the FFI. (Note: if the track-star is in the FPI, corrections for chop throw instabilities can be made, which can’t be made if the track-star is in the FFI.) Once the mode is set-up, the observer can select which image of the sky to observe and map with tracking enabled if desired.

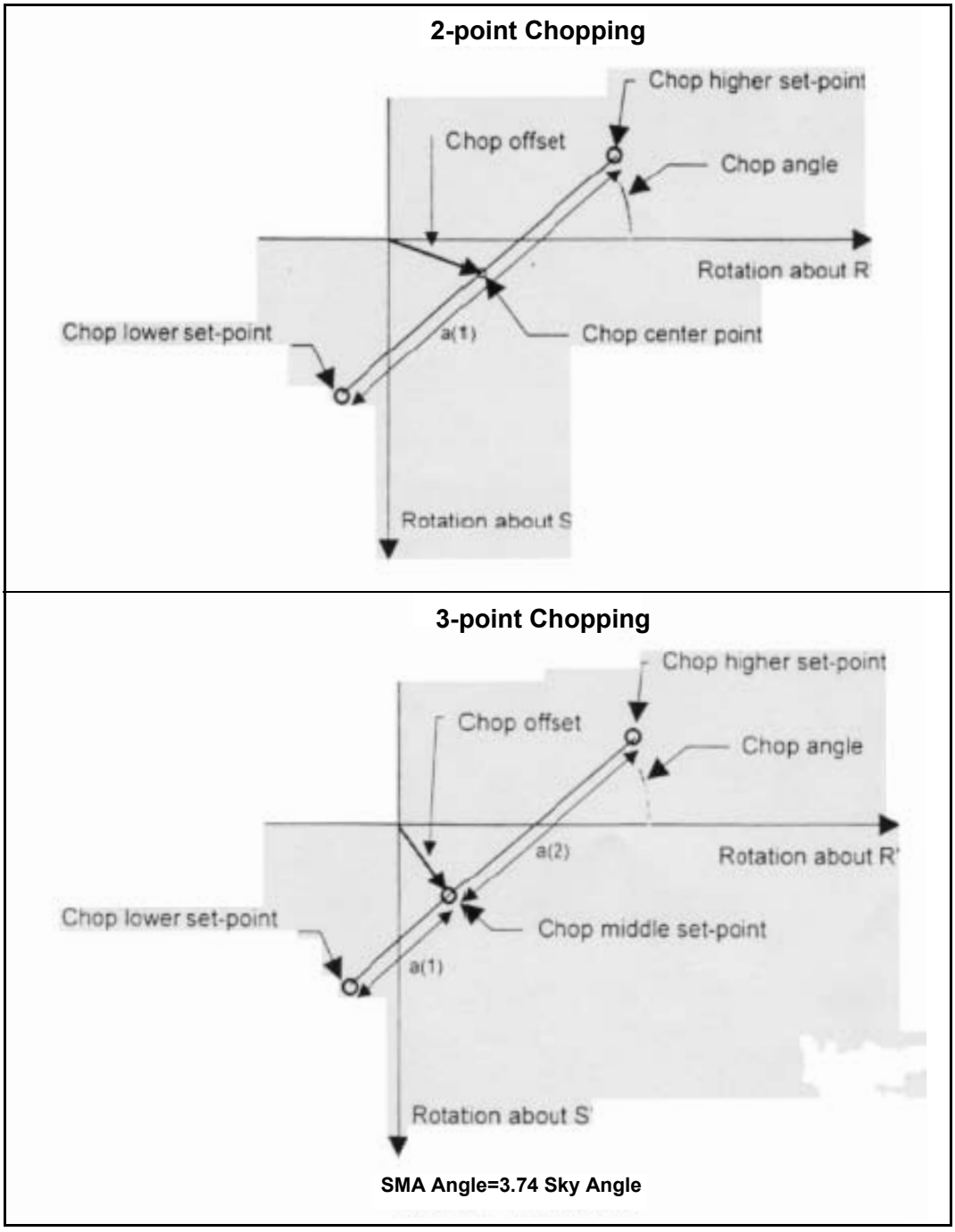


Figure 4-6. Two and Three Point Chopping on the Sky

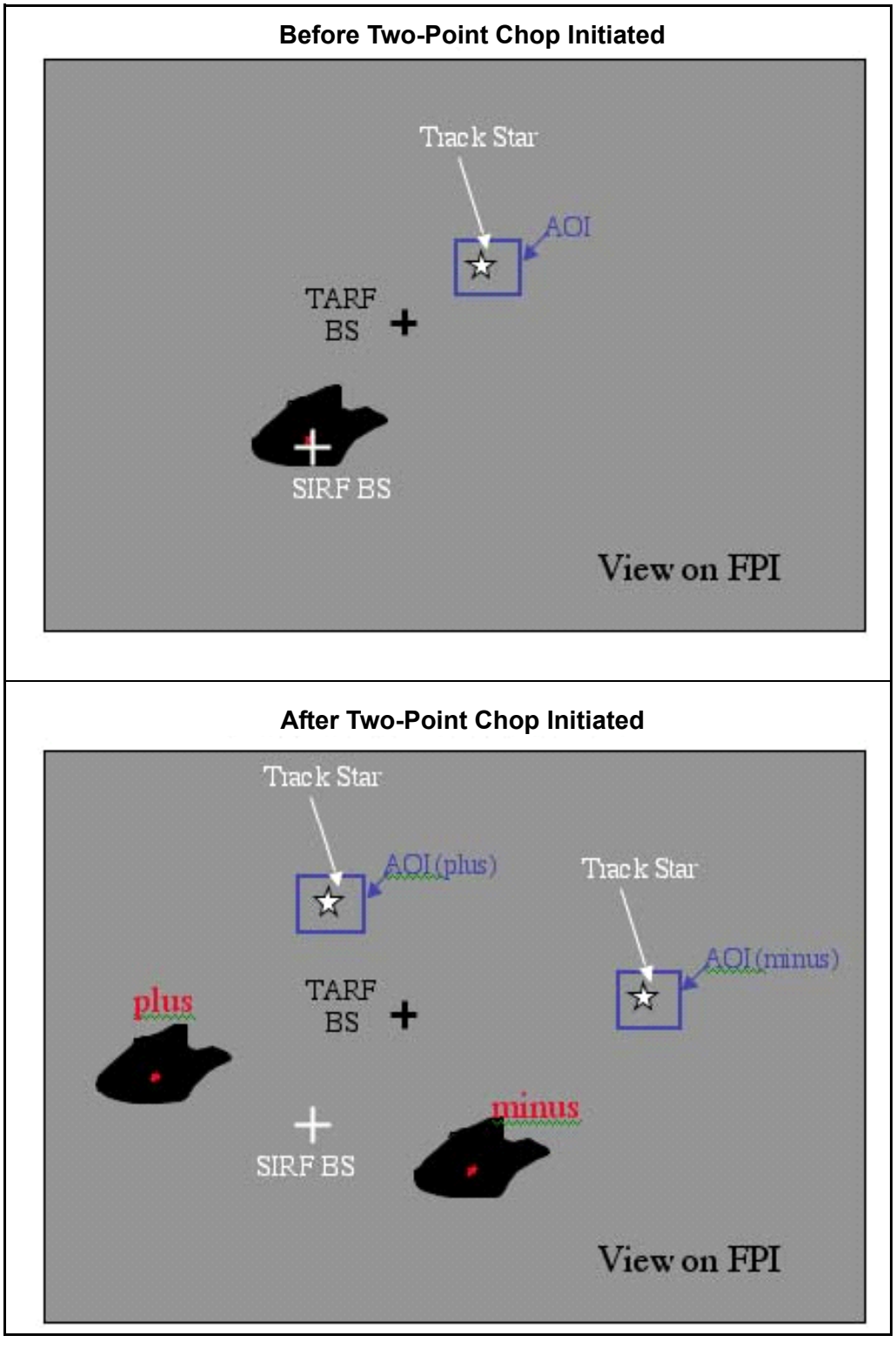
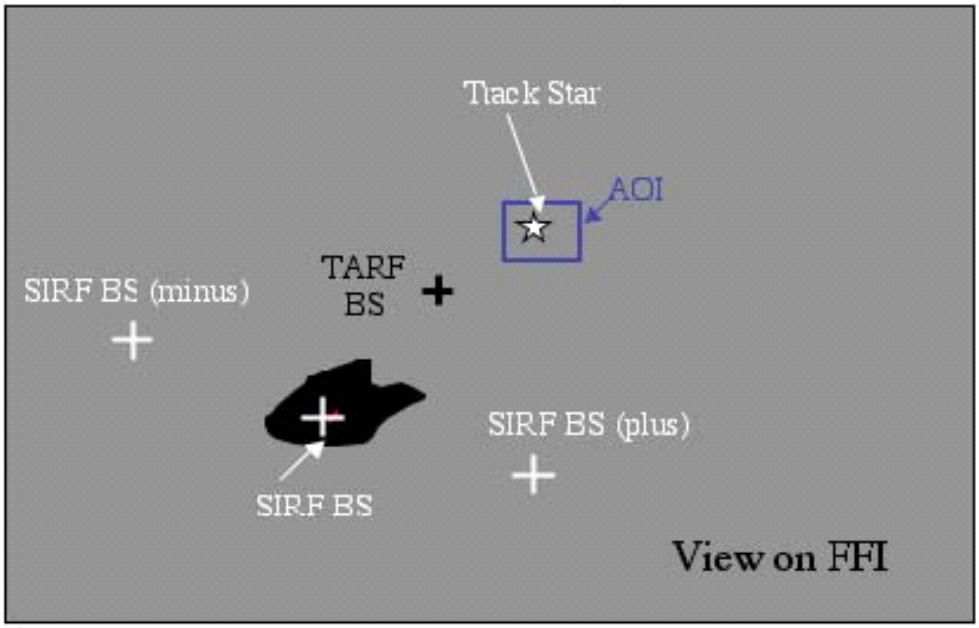


Figure 4-7. View from Focal Plane When Two-Point Chopping

After Two-Point Chop Initiated



After moving SI Boresight to plus image of IR Source

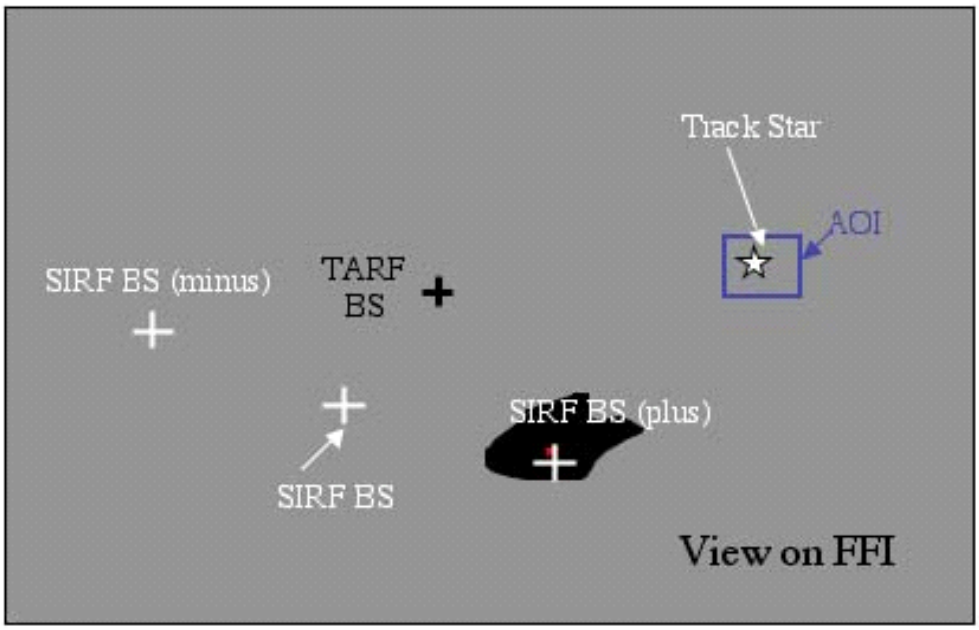


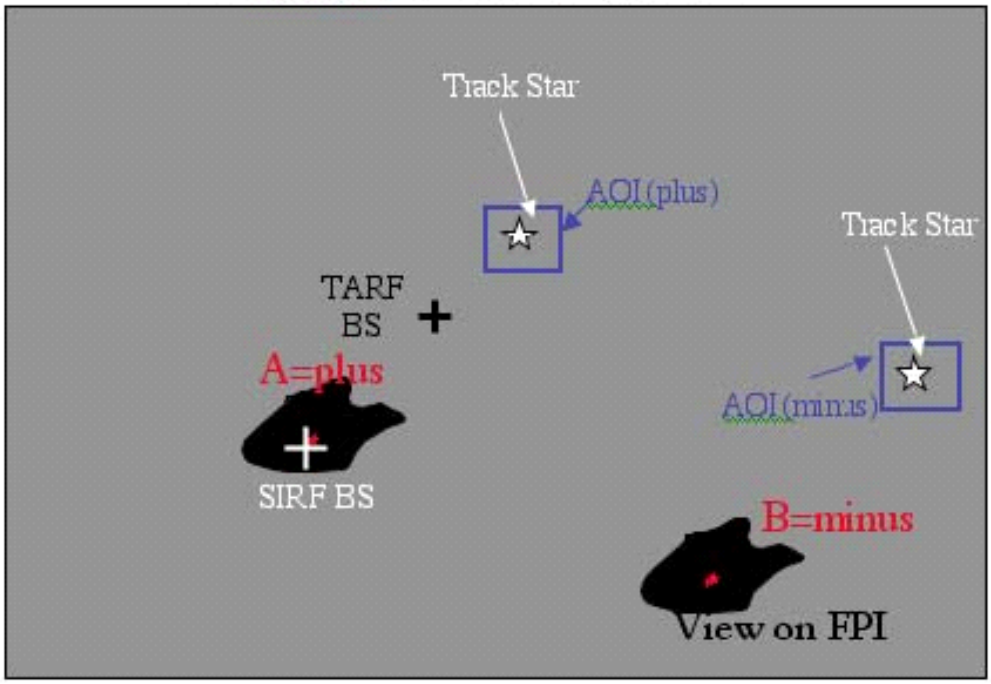
Figure 4-8. Two-Point Chopping when Track-Star in FFI

4.5.3.5 - Nod/Chop Mode

In this mode, the chopper (i.e., the TCM) is under a control loop tip/tilt oscillation, and the observer wishes to move the SI boresight from one image of an IR source to the next in a prescribed sequence, taking data while the SI boresight is on each image. This is a combination of the nod-mode and chop-mode, where the nod-beams coincide with the chop-beams. Figure 4-9 illustrates this combination for a two-point chop. The nod-sequence is defined so the nod-beams coincide with the positions on the sky where the SI boresight is positioned to look at the different chopped images of the IR source of interest.

The observer can also map with pre-defined offsets, such that these offsets will be simultaneously made in all chopped images and defined nod-beams.

SI Boresight in Beam A (using the FPI)



SI Boresight in Beam A (using the FFI)

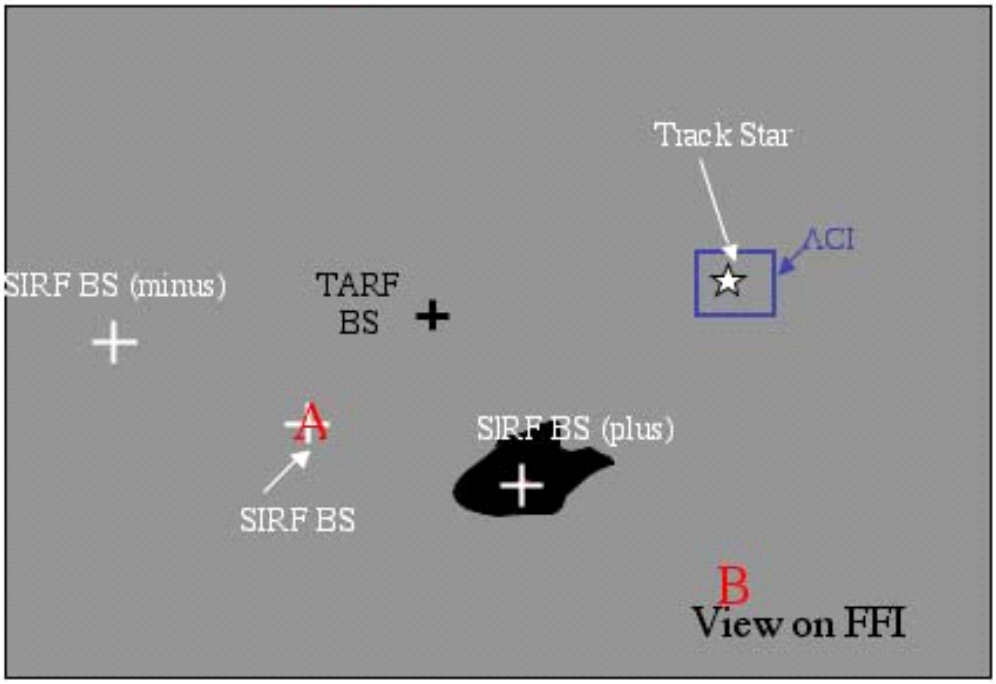


Figure 4-9. Two- Beam Nod/Chop Set-up

4.5.3.6 - Scan Modes

In these modes, the chopper (i.e., the TCM) can either be under a control loop tip/tilt oscillation or not.

There are two scan modes:

1) Scanning to “explore”

2) Scanning to take data

When an observer wishes to do a quick scan set-up to explore an IR source or explore possible scan set-up parameters, he/she can use an SCL command that can scan the sky using a number of different coordinate systems, scan-rates, and scan-paths. However, when an observer wants to record data while scanning, there is a better command allowing the observer to define, in a number of coordinate systems, a start and end-point of a scan, a scan-rate, and the precise time for the start-point to be crossed by the scan.

This “data taking scan command” will scan using a great-circle between the two end-points of the scan. The scan-rate is guaranteed from the very start of the scan to the very end, since a ramp-up and ramp-down are automatically added to the ends of the required scan path to ensure the scan-rate along the entire scan path. This command also gives, as “broadcast” housekeeping, the exact time the start- and end-points are crossed. This is in addition to the normal housekeeping data giving the position of the SI boresight on the sky, which is updated every 20 milliseconds and time stamped.

At ORR, will only be able to execute great-circle, constant-velocity scans, but soon after ORR will have the capability to map out any pattern on the sky (within the maximum speed limits of the telescope, i.e., < 1 degree/sec).

Figure 4-10 illustrates a “data-taking” constant-velocity scan while chopping. This scan allows an observer to specify which of the chopped images of the IR source the SI boresight should scan. The scan also allows an observer to specify how many times the scan should be repeated, and if a return path should also be used.

At ORR, there will not be SCL in place to set up an automatic raster scan, but an effective raster scan can be produced by making a sequence of “data-taking” scans, each offset from the previous scan, and each keying off the broadcast housekeeping announcing the end of the previous scan.

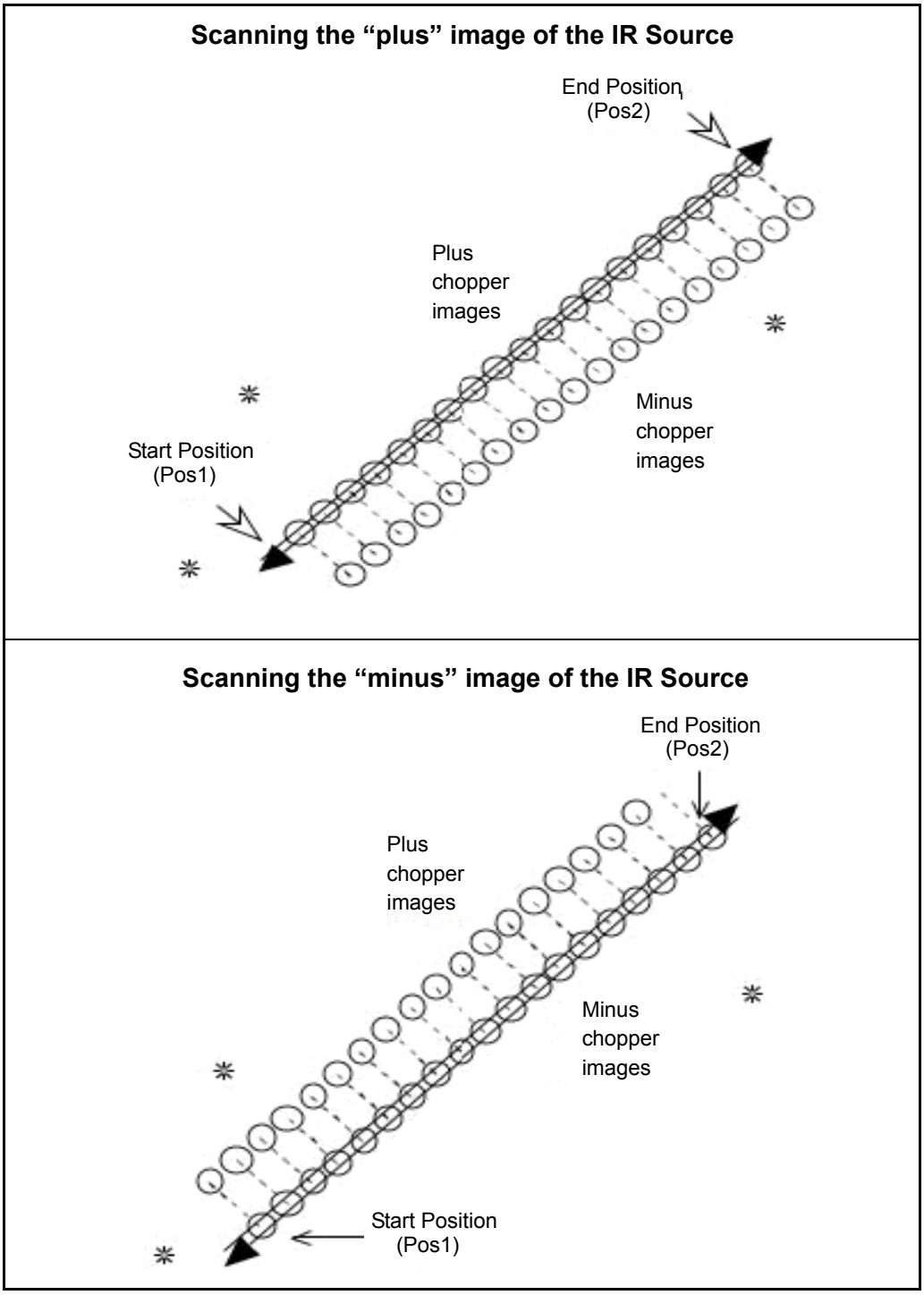


Figure 4-10. Scanning while Chopping

4.5.3.7 - Various Mapping Options

MCS (through SCL and/or GUIs) will support both absolute and relative (i.e., offset) mapping using the telescope. At ORR, mapping using the Secondary Mirror will only be possible using analog signals from the SI (see section 5.3.4). But in this latter case, the MCS has no knowledge of the position on the sky of the SI boresight. This must be followed by the SI.

****** COMMENT *** Link to section 5.3.4? Is this correct?***

Absolute and offset mapping can be done while chopping and/or nodding. The observer can specify which chopped image and/or nod position the SI boresight is in when mapping.

Both absolute map positions and map offsets may be pre-defined. Thus mapping sequences can be set-up in advance. Mapping can be carried out using a number of different coordinate systems, notably the following:

- Equatorial Reference Frame (i.e., RA and Dec)
- Ecliptic Reference Frame (i.e., Lambda, Beta)
- Galactic Reference Frame (i.e., l, b)
- Telescope Reference Frame w.r.t. Aircraft Reference Frame (i.e., EL, XEL, and LOS)
- WFI Reference Frame
- FFI Reference Frame
- FPI Reference Frame
- SI Reference Frame

CHAPTER 5

SOFIA SI Proposal and Review Process

5.1 USRA SOFIA Science Instrument Proposal Process 5-2
5.2 Evaluation Criteria (In Approximate Order of Importance) 5-4
5.3 Guidelines for Participation in the Instrument Program 5-5
5.4 USRA Review Process During SI Development 5-17
5.5 Project Implementation Plan 5-19

**** COMMENT *** Dates, Names, and Addresses, need review in this chapter*

5.1 - USRA SOFIA Science Instrument Proposal Process

5.1.1 - Classes of Science Instruments Considered for Development

In a Call For Proposals (CFP) for SOFIA, four classes of science instruments will be considered for development: Facility-class instruments (FSI), Principal Investigator-class instruments (PSI), Special Purpose PI-class instruments (SSI) and Facility Support Equipment. For the purpose of this Call for Proposals, the four classes of instruments are defined as follows.

5.1.1.1 - Facility-class Science Instrument (FSI)

This is a general purpose, reliable and robust instrument that provides state-of-the-art science performance at commissioning, through the use of modern but mature technologies. The capabilities of a PSI should be focused on a single, well-defined science and technology theme. It is expected that this instrument will routinely be operated by the designated SSMOC (SOFIA Science and Mission Operations Center) FSI scientist in support of Guest Investigators (GI's) who will not be required to have extensive knowledge or experience in infrared instrumentation or observing techniques. Routine maintenance will be provided by the SSMOC, where the instrument will be housed during extended periods. Major maintenance and/or upgrades may be provided by either the PI or the SSMOC, as proposed. Descriptive documentation must be clear, thorough, and intuitive so that a GI can propose a science investigation without the necessity of extensive discussion with the SSMOC FSI scientist or the PI team. The process of data acquisition, reduction, and calibration should be straightforward and transparent to the GI, with the assistance of the SSMOC PSI scientist. The GI should be able to perform data analysis of calibrated data using standard software routines, without requiring the assistance of the SSMOC FSI scientist A simple method of archiving a summary of the observations and the science data will be required. A preliminary design review, a critical design review; and an acceptance review will be held by USRA for FSIs. The instrument will be delivered to the SSMOC.

5.1.1.2 - Principal Investigator-class Science Instrument (PSI)

This is a general purpose instrument that is developed and maintained at the state of the art throughout its useful operating life. It is expected that this instrument will be operated by the PI team; both for its own research as well as for that of successful GI's. The interaction of the PI and GI teams is to be determined by mutual consensus for each GI proposal. Normally the instrument will reside at the PI's institution, where all maintenance and upgrades will be accomplished. Descriptive documentation must be clear, thorough, and intuitive so that a GI can propose a science investigation without the necessity of extensive discussion with the PI team. The process of data acquisition, reduction, and calibration should be straightforward and transparent to the GI, requiring only a minimal level of assistance from the PI team. The GI should be able to perform

data analysis of calibrated data using standard software routines, such as IRAF, without requiring the assistance of the PI team. A simple method of archiving a summary of the observations will be required.

5.1.1.3 - Special Purpose Principal Investigator-class Science Instrument (SSI)

This is a special purpose instrument, specifically designed for a particular observation or set of observations not possible or practical with FSI or PSI instruments. This instrument may incorporate technologies at the "edge-of-the-art" that would be too risky to include in a general purpose instrument. It is expected that this instrument will be operated by the PI team. Normally the instrument will reside at the PI's institution, where all maintenance and upgrades will be accomplished. Descriptive documentation must be extensive enough so that a potential GI can determine the feasibility of his/her proposed observation.

5.1.2 - Facility Support Equipment

In addition, consideration will be given to proposals for general purpose devices for the facility. For example; at least four of the successful SOFIA study grants indicated an interest in an instrument rotator. It is not cost effective to build independent instrument rotators for each instrument. Therefore, USRA would welcome proposals for a facility rotator. A similar situation could also occur with common back-ends for heterodyne spectrometers. Proposals for facility support equipment must: (1) clearly show the demand for the equipment being proposed; and (2) summarize equipment specifications required in order to meet this demand. The estimated cost for the equipment should be compared to the cost that would have been accrued by USRA if similar equipment had been built by each PI team who required it.

Any approved SOFIA science instrument must also be accompanied by the complete set of documentation required for FAA certification, as well as documentation showing compliance with the Interface Control Documents that assure compatibility with the Observatory (See Appendix E). This documentation is NOT required for purposes of this proposal.

In the case of FSI's, commissioning time will be granted. The proposer should put in a draft plan for the commissioning and the expected flight hours needed. The actual number of commissioning flight hours granted will be negotiated between the P.I. and USRA during development. To compensate for the large effort needed to build a FSI, a flight reward of 50 Successful Flight Hours (SFH) will be given the successful P.I. Team, during the first 2 years. This assumes the nominal 600 SFH/year is achieved in the first two years of operation. Upon review of the instrument performance, additional grant awards of no more than $100K per year for two years will be considered for PIs that have successfully delivered an instrument. The P.I. must supply a cost proposal for these awards through a future CFP.

For PSI's and SSI’s, 30 hours of engineering time on SOFIA will be provided to bring the

instrument on line. This time will also be considered as a reward for building the instrument.

Additional science time can be requested once the instrument is operational, through future CFP's.

Proposals for the development of FSI' s may also include an option for a PSI, in the event that the instrument is not selected as an FSI. In the proposal review process, all proposals will be considered and discussed at once. At that point a decision will be made to select one to three FSI's. Unsuccessful FSI proposals that have included the PSI option will then be considered for selection with the remaining PSI proposals. Such proposals must include a clear statement of how the PSI would differ from the PSI and must also include a detailed budget for the PSI option.

Finally, because funds are very limited for this CFP, USRA would like to strongly encourage cost and science effectiveness in the proposed instruments. Examples would be:

1) Real cost sharing with the proposers institution.
2) Building extensively on past space and ground-based experience and equipment.
3) Building extensively on past KAO experience and equipment.

5.2 - Evaluation Criteria (In Approximate Order of Importance)

1. Scientific merit and technical feasibility.

a. For FSI's: Scientific merit across a broad range of science that will serve the general astronomy community, plus specific merit of the science proposed by the PI team. The case for significant demand of the instrument by the community should be made. Technical feasibility win include reliability, ease of operation, robustness of design and fabrication, and maturity of the technology.

b. For PSI's: Scientific merit of the PI team's proposed investigation; capability of the instrument to support science investigations other than the PI team's science. Technical feasibility will include reliability, robustness of design, maximum scientific performance.

c. For SSI's: Scientific merit of the PI team's proposed investigation. Technical feasibility will include reliability and design for maximum scientific performance.

2. Need for SOFIA to carry out the proposed research program

3. The estimated development and two-year operational cost of the instrument. For PSI instruments this should include estimated costs for the SSMOC and SSMOC personnel, as well as the PI team.

4. The capabilities and experience of the investigators, and the suitability of available facilities and support staff for the proposed instrument development.

5. For PSI's and SSI's: The potential benefits of new technology developments that will be incorporated in the instrument, together with their associated risks and cost impacts. Technology development specific to the instrument should be clearly described.

6. Education and Public Outreach. It is advantageous for proposals submitted in response to this CFP to include a plan for interfacing with, and complementing, the SOFIA Education and Public Outreach Activities (E/PO). Two examples of the items to incorporate are: 1) a channel to make, selected and prepared data publicly available for purposes of education and public information (including formats appropriate for the press) and 2) a time commitment by instrument team members to interact locally with teachers and students in a specified manner that furthers the goals of E/PO. Further examples will be posted on the website.

- The points listed above should be addressed in a direct, organized and concise manner.
- For Facility Support equipment, only 3, 4, and 5 above are appropriate.
- Functional overlap of a science instrument proposed in response to this CFP with a proposed SOFIA German instrument will NOT be an issue and will NOT be considered in the evaluation for this CFP. A current list of possible German instruments can be obtained by request to USRA.

5.3 - Guidelines for Participation in the Instrument Program

5.3.1 - Purpose

These guidelines provide procedural and format information for submission of proposals to the SOFIA Science Instrument Program.

5.3.2 - Period of Performance

All proposals will be considered for a period of performance necessary to design and develop the proposed instrument, and to operate the instrument for the first two years of SOFIA science operations. (See Appendix E for schedule)

5.3.3 - Proposal Format and Content

5.3.3.1 - Proposal Content

The proposal should contain at least the following material assembled in the order given:

1. Cover Letter: One copy of the proposal shall be designated as the official copy and should be prefaced by a cover letter signed by an official of the investigator's organization who is authorized

to commit the organization to the proposal and its content. The cover letter should refer to the proposal for "SOFIA Science Instrument Development" and reference USRA ID# CFP97 -001.

2. Title page: The title page must contain:

a. Identification of the CFP, by number and title, to which title proposer is responding;
b. A brief, scientifically valid project title intelligible to a scientifical1y literate reader and suitable for use in the public press;
c. The legal name and address of the organization and specific division or campus identification if part of a larger organization;
d. Names and telephone numbers of the principal investigator and of appropriate business personnel who may be contacted during evaluation or negotiation;
e. The name(s) and affiliation of co-investigator(s). (Use a second page if necessary)
f. Date of submission; and
g. Signature of a responsible official or authorized representative of the organization, or any other person authorized to legally bind the organization.

1 Abstract and Proposal Summary: The Title Page should be followed by the Abstract and Proposal Summary page. The format for this page is given in Section 3.6.

2 Description of Proposed Research (FSI Proposals): The main body of the technical proposal should follow the Abstract and Proposal Summary page. FSI proposals should contain concise descriptions of:

a. the key scientific research areas that the instrument will explore;

b. the scientific strength of the community that will be served by the instrument;

c. the instrument concept, its potential, performance, reliability, and user-friendliness;

d. why the instrument is well-suited to the research goals;

e. why SOFIA is required to carry out the research;

f. a discussion of the construction and operating costs of the instrument;

g. a description of the facilities and personnel available for the instrument development;

h. the management plan for the instrument development and operation;

i. the proposed Education and Public Outreach activities. FSI proposals may optionally contain a discussion of how the instrument and its development and operation plans would change if the proposers wish to have it considered as a PSI if it is not selected as a PSI.

3. PSI and SSI Proposals: PSI and SSI proposals should contain concise descriptions of:

a. the key scientific research areas that the instrument will explore;

b. the instrument concept, its potential performance, and reliability;

c. the technology readiness and technology development plan;

d. why the instrument is well-suited to the research goals;
e. why SOFIA is required to carry out the research;

f. a discussion of.the construction and operating costs of the instrument and the uncertainties in these costs;

g. a description of the facilities and personnel available for the instrument development;

h. the proposed Education and Public Outreach activities.

The difficult choices that must be made between instrument study proposals will require an evaluation of estimated system performance, including sensitivity, field of view, spectra] range, and resolution. Each proposal should provide an estimate of these quantities that is understandable to the peer review panel.

5.3.3.2 - Proposal Length

The proposal body should be double-spaced using a 12 point font and have 1 inch margins on all sides. Pages that fold-out are not acceptable. Each page should be numbered consecutively and a table of contents should be provided. Facility Class Science Instrument proposals shall be limited to 60 pages. Principal Investigator Class Science Instrument and Special Purpose Principal Investigator Class Science Instrument proposals shall be limited to 30 pages. Facility Support Equipment shall be limited to 15 pages. The page limit for all proposals includes the abstract, text, figures, tables, references and any appendices, but does not include the title page, the table of contents page, the budget and its explanation, vitae, and certification attachments. Reprints and preprints should **not** be included with the proposal. Prior results that are relevant to the proposal should be referenced and/or concisely summarized in the text.

Note: All proposals that do not meet these page requirements will be returned to the proposer.

5.3.3.3 - Cost Plan

If USRA funding support is required, a cost plan prepared as shown in Appendix D should be submitted. The total cost of the proposed development should also be reported on the Abstract and Summary Page. Instructions for preparing cost plans are as follows:

1. Proposals should contain cost and technical parts in one volume: do not use separate “confidential” salary pages. As applicable, include separate cost estimates for salaries and wages; fringe benefits; equipment; expendable materials and supplies; services; domestic and foreign travel; publication or page charges; consultants; subcontracts; other miscellaneous identifiable direct costs; and indirect costs. List salaries and wages in appropriate organizational categories (e.g., principal investigator, other scientific and engineering professionals, graduate students,

research assistants, and technicians and other non-professional, personnel). Estimate all man-power data in terms of man-months. The cost plan for SOFIA instrument development proposals should include the cost of one trip per year to a SOFIA Instrument Proposers' Meeting at Moffett Field, CA or Waco, TX.

2. Explanatory notes should accompany the cost proposal to provide identification and estimated cost of major capital equipment items to be acquired; purpose and estimated number and lengths of trips planned; basis for indirect cost computation (including date of most recent negotiation and cognizant agency); and clarification of other items in the cost proposal that are not self-evident. List estimated expenses as yearly requirements by major work phases.
3. For all questions concerning allowable costs, proposers should contact: Robert Senter, USRA, 10227 Wincopin Circle, Suite 212, Columbia, MD 21044, Phone: (410) 730-2656") Fax: (410) 730-3496, E- mail: rsenter@hq.usra.edu.

5.3.3.4 - Current Support

For other current projects being conducted by the principal investigator, provide title of project sponsoring agency, and ending date.

5.3.3.5 - Vitae

Vitae and publications together are limited to a minimum of **one page per individual** for the PI and CoI's, and the individual publications are limited to the five most relevant to the proposal plus five others that the PI or CoI may wish to include.

5.3.4 - Certifications

The Certifications provided in the Attachments should be filled out and attached to the original copy of the proposal. This will reduce the amount of time required to process grants.

5.3.5 - Additional Guidelines for Foreign Proposers And Proposals With Foreign Participation

In this Call for Proposals, USRA is not soliciting proposals for instrument development from PI teams from non-U.S. institutions. Should such a non-U.S. PI team wish to develop an instrument for use on SOFIA, USRA will provide them with the same technical information made available to U.S. proposers. Such non-U.S. teams may then propose for time on SOFIA with their instrument on a future Call for Proposals. Should a U.S. proposal with non-U.S. participation be selected, USRA will arrange with the non-U.S. sponsoring agency for the proposed participation on a no exchange of funds basis, in which USRA and the non-U.S. sponsoring agency will each bear the cost of discharging its respective responsibilities. U.S. proposals which include non-U.S. participation must be endorsed by the respective government agency or funding/sponsoring institution of the country from which the non-U.S. participant is proposing. Such endorsement should be in the form of a letter attached to each copy of the proposal and should indicate:

1. The proposal merits careful consideration by USRA; and

2. If the proposal is selected, sufficient funds will be made available to undertake the activity as proposed.

Proposals must be forwarded to USRA in sufficient time to arrive before deadline established for this Call For Proposals.

All proposals must be in English. All U.S. proposals which include non-U.S. participation must follow all other guidelines and requirements described in this CFP.

5.3.6 - Additional Policies And Procedures

1. Restriction on Use and Disclosure of Proposal Information: In order to protect trade secrets or other proprietary information that is confidential or privileged, such information should be clearly identified and marked in the proposal. In any event, all efforts will be made to protect information contained in proposals; but USRA assumes no liability for use and disclosure of information not clearly marked as proprietary. A solicited proposal that results in a USRA award becomes part of the record of that transaction and may be available to the public on specific request; however, information or material that USRA and the awardee mutually agree to be of a privileged nature will be held in confidence to the extent permitted by law.
2. Conformance to Guidance: USRA does not have mandatory forms or formats for responses to CFPs; however, it is requested that proposals conform to the guidelines in these instructions. USRA may accept proposals without discussion; hence, proposals should initially be as complete as possible and be submitted on the proposers' most favorable terms.
3. Joint Proposals: Where multiple organizations are involved, the proposal must be submitted by only one of them. It should clearly describe the role to be played by the other organizations and indicate the legal and managerial arrangements contemplated.
4. Late proposals: A proposal or modification received after the due date specified in this CFP will not be considered.
5. Withdrawal: Proposals may be withdrawn by the proposer at any time. Offerors are requested to notify USRA if the proposal is funded by another organization or of other changed circumstances which dictate termination of evaluation.
6. Selection for Award: When a proposal is not selected for award, the proposer will be notified. USRA will explain generally why the proposal was not selected. Proposers desiring additional information may contact the Chief Scientist who will arrange a debriefing. When a proposal is selected for award, negotiation and award will be handled by the USRA Contracts Manager.
7. Cancellation of CFP: USRA reserves the right to make no awards under this CFP and to cancel this CFP. USRA assumes no liability for canceling the CFP or for anyone's failure to receive actual notice of cancellation. Cancellation may be followed by issuance and synopsis of a revised CFP, if that is appropriate.

5.3.7 - Proposal Forms

Proposal Title Page

_____Proposa1 Reference No.
(To be filled in by USRA)

TITLE OF
PROPOSAL: _____

ABSTRACT

SOFIA INSTRUMENT DEVELOPMENT PROPOSAL SUMMARY

Principal Investigator: _____
Organization: _____
Phone *I* Fax *I* Email: _____
Type of Organization (e.g. profit, non-profit, educational, small business. minority, woman-owned, etc.): _____
Identification of other organizations, if any, that are currently evaluating a proposal for the same efforts: _____
Instrument Type: _____
Detector Type: _____
Detector Format: _____
Wavelength Range: _____
Resolution/Pass Bands: _____
Funds Requested from USRA for Duration of Project and the Desired Starting Date: _____

Figure 5-1. Proposal Form: Proposal Title Page

Budget Summary

From _____ To _____

	USRA USE ONLY		
	A		
1. Direct Labor (salaries, wages, and fringe benefits)			
2. Other Direct Costs:			
a. Subcontracts			
b. Consultants			
c. Equipment			
d. Supplies			
e. Travel i) Domestic			
ii) Foreign			
f. Publication			
g. Other			
3. Indirect Costs			
4. Other Applicable Costs			
5. Subtotal -- Estimated Costs			
6. Less Proposed Cost Sharing (if any)			
7. Total Estimated Costs			
APPROVED BUDGET	XXXXXXXXX		

Figure 5-2. Proposal Form: Budget Summary

5.3.7.1 - Instructions for Budget Summary Form

1. Provide a separate budget summary sheet for each year of the proposed development program.
2. Estimated costs should be entered in Column A. Columns B and C are for USRA use only.

5.3.7.1.1 - Explanation of Proposed Costs

Provide in attachments to the budget summary the detailed computations of estimates in each cost category, along with any narrative explanation required to fully explain proposed costs.

A. Direct Costs

Direct Labor (salaries, wages, and fringe benefits). Attachments should list number and titles of personnel, amount of time to be devoted to the grant, rates of pay, and an estimate of labor hours for each position.

Subcontracts: Attachments should describe the work to be subcontracted, estimated amount, recipient (if known), and the reason for subcontracting this effort.

Consultants: Identify consultants to be used, why they are necessary, time to be spent on the project, and rates of pay.

Equipment: List separately and explain the need for items of equipment exceeding $5,000. Describe the basis for the estimated cost. General purpose; non-technical equipment is not allowable as a direct cost to USRA grants unless specifically approved by the contracting officer.

Supplies: Provide general categories of needed supplies, the method of acquisition, estimated cost, add the basis for the estimate.

Travel: List proposed trips individually, describe their purpose in relation to the grant, provide dates, destination, and number of travelers where known, and explain how the cost for each was derived.

Publications: Detail publication costs, if any, listing page changes, etc.

B. Other

Enter the total of any other direct costs not covered by 2.a through 2.f.
Attach an itemized list explaining the need for each item and the basis for the estimate.

C. Indirect Costs

Identify indirect cost rate(s) and base(s) as approved by the cognizant Federal agency, including the effective period of the rate. Provide the name, address, and telephone number of the Federal agency and official having cognizance over such matters for the institution. If unapproved rates are used, explain why and include the computational basis for the indirect expense pool and corresponding allocation base for each rate.

D. Other Applicable Costs

Enter the total of any other applicable costs.
Attach an itemized list explaining the need for each item and the basis for the estimate.

E. Subtotal-Estimated Cost

Enter the sum of items 1., 2.a. through 2.f., 3., and 4.

F. Less Proposed Cost Sharing (if any)

Enter the amount proposed, if any. If cost sharing is based on specific cost items, identify each item and amount in attachment. For Total Estimated Cost, enter the total after subtracting item 6 from item 5.

5.3.8 - Additional Proposal Forms and Certifications

5.3.8.1 - Certification Regarding Debarment, Suspension, and Other Responsibility Matters, Primary Covered Transactions

This certification is required by the regulations implementing Executive Order 12549, Debarment and Suspension, 34 CPR Part 85, Section 85.510, Participants' responsibilities. The regulations were published as Part VII of the May 28, 1988 Federal Register (pages 19160~19211). Copies of the regulations may be obtained by contacting the U.S. Department of Education, Grants and Contracts Service, 400 Maryland Avenue, S.W. (Room 3633 GSA Regional Office Building No.3), Washington, D.C. 20202-4725, telephone (202) 732- 2505.

A. The applicant certifies that it and its principals:

(a) Are not presently debarred, suspended, proposed for debarment, declared ineligible, or voluntarily excluded from covered transactions by any Federal department or agency;
(b) Have not within a three-year period preceding this application been convicted or had a civil judgment rendered against them for commission of fraud or a criminal offense in collection with obtaining, attempting to obtain, or performing a public (Federal, State, or Local) transaction or contract under a public transaction; violation of Federal or State antitrust statutes or commission of embezzlement, theft, forgery, bribery, falsification or destruction of records, making false statements, Or receiving stolen property;
(c) Are not presently indicted for or otherwise criminally or civilly charged by a government entity (Federal, State, or Local) with commission of any of the offenses enumerated in paragraph A.(b) of this certification;
(d) Have not within a three-year period preceding this application/proposal had one or more public transactions (Federal, State, or Local) terminated for cause or default; and

B. Where the applicant is unable to certify to any of the statements in this certification, he or she shall attach an explanation to this application.

C. Certification Regarding Debarment, Suspension; Ineligibility and Voluntary Exclusion Lowered Tier Covered Transactions (Sub grants or Subcontracts)

(a) The prospective lower tier participant certifies, by submission of this proposal, that neither it nor its principles is presently debarred, suspended, proposed for debarment, declared ineligible or voluntarily excluded from participation in this transaction by any federal department of agency.
(b) Where the prospective lower tier participant is unable to certify to any of the statements in this certification, such prospective participant shall attach an explanation to this proposal.

Organization Name	CFP or AD Number and Title
Printed Name and Title of Authorized Representative	
Signature	Date
Printed Principal Investigator Name	Proposal Title

5.3.8.2 - Certification Regarding Drug-Free Workplace Requirements

This certification is required by the regulations implementing the Drug- Free Workplace Act of 1988, 34 CFR Part 85. Subpart F. The regulations, published in the January 31, 1989 Federal Register, require certification by grantees prior to award, that they will maintain a drug-free workplace. The certification set out below is a material representation of fact upon which reliance will be placed when the agency determines to award the grant. False certification or violation of the certification shall be grounds for suspension of payments, suspension or termination of grants, or government-wide suspension, or debarment (see 34 CFR Part 85, Sections 85.615 and 85.620).

I. GRANTEES OTHER THAN INDIVIDUALS

A. The grantee certifies that it will provide a drug-free workplace by:
(a) Publishing a statement notifying employees that the unlawful manufacture, distribution, dispensing, possession or use of a controlled substance is prohibited in the grantee's workplace and specifying the actions that will be taken against employees for violation of such prohibition;
(b) Establishing a drug-free awareness program to inform employees about—

(1) The dangers of drug abuse in the workplace;
(2) The grantees policy of maintaining a drug-free workplace;
(3) Any available drug counseling, rehabilitation, and employee assistance programs; and
(4) The penalties that may be imposed upon employees for drug abuse violations occurring in the workplace;

(c) Making it a requirement that each employee to be engaged in the performance of the grant be

given a copy of the statement required by paragraph (a);
(d) Notifying the employee in the statement required by paragraph (a) that, as a condition of employment under the grant, the employee will

(1) Abide by the terms of the statement; and
(2) Notify the employer of any criminal drug statute conviction for a violation occurring in the workplace no later than five days after such conviction;

(e) Notifying the agency within ten days after receiving notice under subparagraph (d) (2) from an employee or otherwise receiving actual notice of such conviction;
(f) Taking one of the following actions, within 30 days of receiving notice under subparagraph (d) (2), with respect to any employee who is so convicted --

(1) Taking appropriate personnel action against such an employee, up to and including termination; or
(2) Requiring such employee to participate satisfactorily in a drug abuse assistance or rehabilitation program approved for such purposes by a federal, State, or Local health, Law enforcement, or other appropriate agency;

(g) Making a good faith effort to continue to maintain a drug-free workplace through implementation of paragraphs (a), (b), (c), (d), (e), and (f).

B. The grantee shall insert in the space provided below the site(s) for the performance or work done in connection with tile specific grant:

Place of Performance (Street address, city, county, state, zip code)

_____

_____

Check _____if there are workplaces on file that are not identified here.

II. GRANTEES WHO ARE INDIVIDUALS

The grantee certifies that, as a condition of the grant, he or she will not engage in the unlawful manufacture, distribution, dispensing, possession or use of a controlled substance in conducting any activity with the grant.

Organization Name	CFP or AD Number and Title
Printed Name and Title of Authorized Representative	
Signature	Date
Printed Principal Investigator Name	Proposal Title

5.3.8.3 - Certification Regarding Lobbying

As required by S 1352 Title 31 of the U.S. Code for persons entering into a grant or cooperative agreement over $100,000, the applicant certifies that:

(a) No Federal appropriated funds have been paid or will be paid by or on behalf of the undersigned, to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, in connection with making of any Federal grant, the entering into of any cooperative, and the extension, continuation, renewal, amendment) or modification of any Federal grant or Cooperative agreement;

(b) If any funds other than Federal appropriated funds have been paid or will be paid to any person for influencing or attempting an officer or employee of any agency, Member of Congress, or an employee of a Member of Congress in connection with this Federal grant or cooperative agreement, the undersigned shall complete Standard Form ~ LLL, "Disclosure Form to Report Lobbying," in accordance with its instructions.

(c) The undersigned shall require that the language of this certification be included in the award documents for all sub-awards at all tiers (including sub-grants, contracts under grants and cooperative agreements, and subcontracts), and that all sub-recipients shall certify and disclose accordingly.

This certification is a material representation of fact upon which reliance was placed whet) this transaction was made or entered into. Submission of this certification is a prerequisite for making or entering into this transaction imposed by 51352, title 31, U.S. Code. Any person who fails to file the required certification shall be subject to a civil penalty of not less than $10,000 and not more th311 $100,000 for each such failure.

Organization Name CFP or AO Number and Title

Printed Name and Title of Authorized Representative

Signature Date

Printed Principal Investigator Name Proposal Title

5.4 - USRA Review Process During SI Development

SOFIA instrument review policy is intended to facilitate the development of world class instruments. The facility instrument program is a key aspect of USRA's plan for a broad-based engagement of the astronomical community within the operational phase of SOFIA. To deliver the instrument performance promised to both NASA and the astronomical community at large, the observatory requires a series of reviews for the facility instrument program. These are: 1) a preliminary design review, 2) a critical design review, and 3) an instrument acceptance review. These reviews are scheduled for mid-1998, mid-1999, and mid-2001, respectively. Within the USRA development program, the facility instrument review program is worked in concert with our internal science support team. The review policies are guided by the past experience of other ground based and space based facilities.

For science instruments, the observatory directory and chief scientist convene reviews. The observatory science support integrated product team supports the review efforts. The observatory director formulates a review board and appoints a chairman to lead the review. The board is instructed to provide constructive comments and avoid extensive problem solving discussions. Recommendations of the board members are captured using request for action forms (RFAs) provided by the observatory.

The review board is responsible for making judgments and recommendations concerning the review content. The board chairman is responsible for supervising the review, mediating discussions, meeting the review objectives, and maximizing the value-added contribution of the review board. Following the review, the board meets to discuss findings, review and assign RFAs, and prepare a draft report. The chairman prepares a final report of concerns and recommendations. The board rejects or adopts either in part or in-full all submitted RFAs from the review.

The principal investigator for the facility science instrument is responsible for a detailed meeting agenda, presenting the material, tending to review logistics, and assembling a hard copy package of the material to be presented at the review. Major concerns of the board following the review are made available to both the PI and the chief scientist/observatory director. The review board chair-

man prepares a final report of the review and delivers the report to the observatory directory within two week of the instrument review. The observatory director following receipt from the board chairman distributes the final report to all meeting attendees.

The basis for the preliminary design review is the development of a project implementation plan (PIP). The PIP is expected to evolve over the life of the project and serves to describe the instrument's form and function to the observatory staff. The PIP is divided into five sections: 1) specification and verification of the instrument requirements and design, 2) required interface control documents, 3) FAA certification plans, 4) project management plans, schedule, and budget, and 5) instrument risk identification, mitigation, and descope. Prior to the preliminary design review, the SOFIA science support IPT is expected to contribute to the formulation of the PIP and provide concurrence on the following issues:

- Preliminary instrument requirements are stated
- Design concepts are feasible and the proposed approach is viable
- Suitable trade study rationale
- Listed problem areas and risks in the proposed approach
- Stated adequacy of schedules, resources, and planning

The primary purpose of the PDR is to verify that the technological implementation satisfies the operational requirements proposed by the instrument teams. The review board verifies that design and fabrication can proceed within allocated costs, schedule, manpower, and facilities. The PDR is scheduled prior to the start of major detailed design activities.

The review board is chartered to look for the following items during PDR:

- Statement of operational requirements
- Verification plans for compliance of requirements
- Identification of inherited designs and standard commercial components
- Major system design parameters (e.g. performance, volume, layout, power, heat, rejection, interfaces, etc.)
- Results of major design tradeoffs with justification of the chosen implementation
- Discussion of key design details including preliminary drawing, sketches, block diagrams, schematics, critical components, software outline and planning, etc.
  Outlines of planned development tests
- Major support equipment requirements
- Preliminary operations planning
- Schedules, budget and status of task
- Major concerns, risks, and descope options
- Open items and resolutions plans

The primary purpose of the CDR is to verify that the detailed design is complete and ready for manufacturing, and that fabrication and testing can proceed within allocated cost, schedule, manpower, and facilities. The review should be scheduled after completion of the design and prior to the fabrication and purchasing. Some long lead items may need to be purchased before this review. The review board should look for the following items during CDR:

- Operational requirements and verification of compliance.
- Summary of major derived design specifications and constraints.
- Response to PDR review board recommendations/concerns.
- Major changes since the PDR
- Interface details and status of agreements
- Selected design details
- Critical component status
- Selected manufacturing details and plans
- Configuration control plans (hardware and software)
- Maintenance plans (hardware and software)
- Documentation status (drawings, documents, procedure)
- Breadboard and prototype test status and results
- Test plans for the deliverable units
- Operational features and constraints
- Spare provisions
- Support equipment requirements, provisions, and plans
- Schedule, budget, and flow plan status
- Major concerns, open items, and plans for resolution

The primary purpose of the acceptance review is to give the final stamp of approval for the instrument as delivered to the SSMOC. The following items should be addressed during the acceptance review:

- Delivery of agreed upon systems (hardware, software, supporting components)
- Verification of expected instrument performance
- Straight forward data acquisition, reduction, and calibration
- Acceptable data archival tools and summary data

5.5 - Project Implementation Plan

To assist the instrument development teams, the science support integrated product team has formulated a standard template for all SOFIA facility instruments to use in the development of a Project Implementation Plan (PIP). The outline addresses all of the review board concerns listed above and provides a standard format for the each team to following in presenting PDR materials. The table of contents for the PIP is as follows:

1. Specification and Verification of Instrument Design
1.1 Final design-to-specifications (level 1)
1.1.1 System design guidelines
1.1.2 System performance parameters
1.1.3 System performance model
1.1.4 Operational constraints
1.2 Design implementation (work break down structure)
1.3 Derived design dependent requirements (level 2) and verification plans
1.3.1 Instrument hardware
1.3.2 Instrument software
1.3.3 Instrument operational concepts
1.4 Facility instrument verification and acceptance plans

2. Required Interface Control Documents
2.1 External Interface Control Documents and Verification Plans
2.2 Internal Interface Control Documents and Verification Plans

3. FAA Certification Plans
3.1 Cryostat
3.2 Instrument mount
3.3 Instrument electronics
3.4 Instrument installation

4. Project management
4.1 Integrated product teams
4.2 Program schedule
4.3 Program budget
4.4 Program deliverables

5 Risk identification, mitigation, descope

Appendix 1. The 1997 Call For Instrument Proposals

This Universities Space Research Association (USRA) Call For Proposals (CFP) solicits research proposals for the design, development, and i1litial operation of scientific instruments for the Stratospheric Observatory For Infrared Astronomy (SOFIA). The Observatory is being developed under the auspices of the National Aeronautics and Space Administration (NASA) under Prime Contract No. NAS2- 97001 and the Deutsche Agentur fur Raumfahrtangelegenheiten (DARA), the German Space Agency. Instruments are being developed separately under the auspices of NASA and DARA.

Participation in this program is open to all categories of organizations, both domestic and foreign: industry, educational institutions, other nonprofit organizations, NASA centers, and other U.S. government agencies. Proposals must be received by **5PM CDT on July 15, 1997.** Late proposals will be handled as correspondence and returned to the sender. The proposals will be evaluated by a USRA-selected peer review panel early in September, 1997, and notification of results will be made approximately one month later.

Details relevant to this program are included in the appendices to this announcement and on the SOFIA-USRA website.

http://sofia-usra.arc.nasa.gov/

Paper copies of the CFP are available from:
J. Kolonko, Science Administrator: Department of Physics and Astronomy
UCLA, 405 Hilgard Ave., Los Angeles, CA 90095
Phone: (310) 206-4548)
FAX: (310) 206-1091
E-mail: kolonko@physics.ucla.edu.

Appendix A describes the classes of instruments being solicited and evaluation criteria. Appendix B contains the general guidelines for participation in the SOFIA Science Instrument Program. Appendix C is the proposal abstract and summary sheet. Appendix D provides a Budget Summary format with instructions for its completion. Appendix E provides technical information on SOFIA to aid in planning instrument proposals. The certification forms in the Attachments should be filled out and attached to the original copy of the proposal to reduce grant processing time.

Schedule of Events:

1. Release of Call for Proposal	April 7, 1007
2. Letters of Intent Due	May 1, 1997
3. FAA Workshop	May 7, 1997
4. Proposal Deadline	July 15, 1997
5. Peer review	Sept. 3-5, 1997
6. Target Date for Announcement of Proposals Selected	Oct. 1, 1997

Future SOFIA CFP's are anticipated. An additional call for major instruments will occur in about 3 years. A technology development program specific to SOFIA, most likely including detector development, will be initiated after the first round of instruments have been selected. Detector development proposals will not be considered in response to this solicitation.

The following items apply only to this Announcement:

CFP Identifier: USRA ID# CFP97-001

Letters of Intent to participate in the CFP are due **May 1, 1997**. Letters of Intent must specify the PI's name and institution, the class of instrument to be proposed (e.g. facility class science instrument, principal investigator class science instrument, etc.)) a brief description of the science instrument) and the science expected from the instrument. The Letter of Intent should also list the names of co-investigators and other collaborative members of the proposing team.

Letters of Intent are to be sent to:

SOFIA Peer Review, Lunar and Planetary Institute, 3600 Bay Area Blvd. Houston, TX 77058-1113

Letters of Intent may be mailed, e-mailed, or faxed to the recipient. FAX: (281) 486-2160, E-Mail: cloud@1pi.jsc.nasa.gov

Submit Proposals to:

SOFIA Peer Review, Attn: Mary Cloud, Lunar and Planetary Institute, 3600 Bay Area Blvd. Houston, TX 77058-1113

Copies Required:

Original plus twenty (20) copies to the address above plus one courtesy copy as discussed below.

Obtain Further Information From:

Technical: Dr. Jacqueline Davidson, Universities Space Research Association, Project Scientist for SOFIA c/o NASA-Ames Research Center, M/S 245-6, Moffett Field, CA 94035-1000 Telephone: (415) 604-5531 E-mail: Davidson @cma.arc.nasa.gov

Administrative: Mary Cloud, Lunar and Planetary Institute, 3600 Bay Area Blvd., Houston, TX 77058-1113, Telephone: 281-486-2143, Fax: 281-486-2160

E-Mail: cloud@lpi.jsc.nasa.gov

In order to facilitate the review process, proposers are strongly urged to send one courtesy copy of their proposal to:

Dr. Eric Becklin, SOFIA Chief Scientist, UCLA Department of Physics and Astronomy, 405 N. Hilgard Ave., Los Angeles. CA 90095-1562

Your interest and cooperation in participating in the SOFIA program are appreciated.

Dr. Paul Coleman, President, Universities Space Research Association

APPENDIX A

Acronyms and Terminology

A-1 Acronyms and Terminology A-1

Table A-1. Acronyms and Terminology

Acronym/Term	Description
AA	Aperture Assembly
AOI	Area of Interest
AOR	Astronomical Observation Request
AOT	Astronomical Observation Template
BSA	Balancing Subassembly
BSB	Boresight Boxes
c.g.	Center of Gravity
CCD	CDDS Cavity Door Drive System
CDDS	Cavity Door Drive System
CDS	Cavity Door System
CECS	Cavity Environmental Control System
cfm	Cubic feet per minute
CLA drape	FC power use is routed over the CLA drape for distribution at the science instrument patch panel.
CODR	Conceptual Design Review
CWR	Counterweight Rack
DAR	Designated Airworthiness Representative
DCR	Document Change Request
DCS	Data Cycle System (SOFIA data acquisition and handling software)
DER	Designated Engineering Representative
DIN	Deutsche Industrie Norm (German Industrial Standard)
EL	Elevation
FA	Flange Assembly
FBC	Flexible Body Compensation
FCM	Focus Centering Mechanism
FCMU	Focus-Controller Mechanism Unit
FFI	Fine Field Imager

Table A-1. Acronyms and Terminology

Acronym/Term	Description
FITS file	Frames of any image from the WFI, FFI, or FPI can be logged in a FITS file.
FM	Flight Management
FMI	Flight Management Infrastructure
FPI	Focal Plane Imager
FSI	Facility Class Instrument
fwd	Forward
GFY	Government Fiscal Year
GI	Guest Investigators
GPS	Global Pointing System
GVPP	Gate Valve Pressure Plate
HK	Housekeeping
HW	Hardware
I/F	Interface
ICD	Interface Control Document
IFD	In-flight Director
IMF	Instrument Mounting Flange
INF	Instrument Flange
INF	Instrument Nasmyth Flange
IR	Infra Red
KNAV	
LFD	Lower Flexible Door
LOS	Line of Sight
LOS	Line-of-Sight
MADA	Mission Audio Distribution System
MCCS PDS	
MCS	Mission Controls Subsystem
NPT	National Pipe Taper (American Standard Pipe Thread)
NT	Nasmyth Tube
ORR	Operational Readiness Review
OSS	Observatory Support Subsystem
PCLS	Portable Chopped Light Source
PDS	Power Distribution System
PI	Principal Investigator
PI Rack	Principle Investigator Instrument Rack
PIF	Pre-Flight Integration Facility
PMA	Telescope Primary Mirror Assembly
PSI	Principal Investigator-class Science Instrument
PWS	Pressure Window Subassembly
RD	Reference Document
RD Seal System	Rigid Door Seal System.
RIS	Rotation Isolation System
ROF	Rotation of the Field
SCL	SOFIA Command Language
SFH	Successful Flight Hours
SI	Science Instrument

Table A-1. Acronyms and Terminology

Acronym/Term	Description
SMA	Telescope Secondary Mirror Assembly
SMCU	Secondary Mirror Control Unit
SOFIA	Stratospheric Observatory For Infrared Astronomy
SSI	Special Purpose Principal Investigator-class Science Instrument
SUA	Suspension Sub-Assembly
TA	Telescope Assembly
TAAS	TAC Time Allocation Committee
TAMCP	TA Master Computer Processor
TASCU	TA Servo Control Unit
TBC	To Be Confirmed
TBD	To Be Determined
TBV	To Be Verified
TCM	Tip/tilt Chopping Mechanism
TCMU	Tilt-Controller Mechanism Unit
TMA	Telescope Tertiary Mirror Assembly
U; V; W	Coordinates of the TA Coordinate System
UAL	United Airlines
UPS	Uninterruptible Power Supply
URD	Upper Rigid Door
USRA	Universities Space Research Association
VDS	Video Distribution System
VIS	Vibration Isolation System
WFI	Wide Field Imager
Wt	Weight
WV	Water Vapor
WVM	Water Vapor Monitor
XEL	Cross Elevation

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